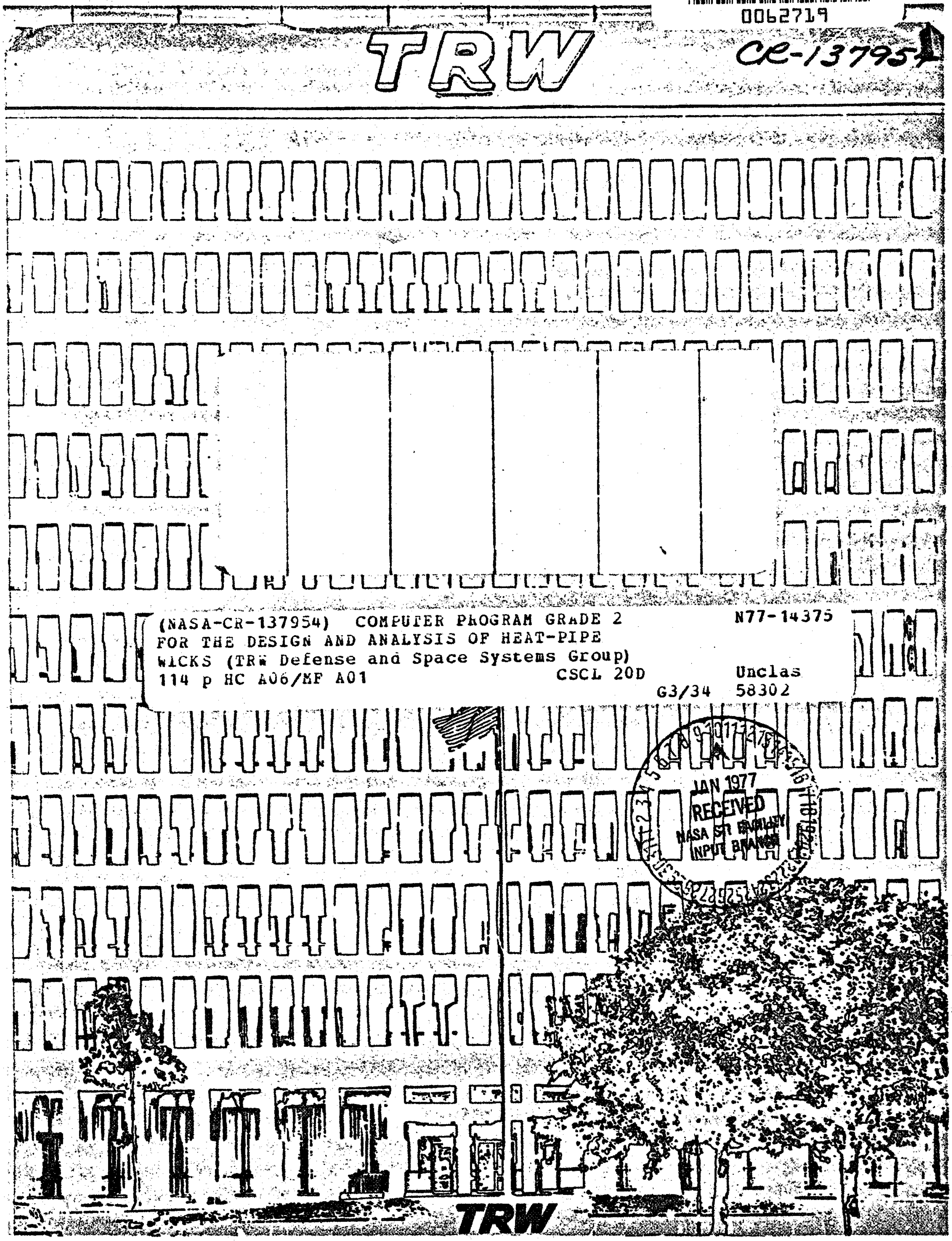
CR-137954



(NASA-CR-137954) COMPUTER PROGRAM GRADE 2 FOR THE DESIGN AND ANALYSIS OF HEAT-PIPE WICKS (TRW Defense and Space Systems Group) 114 p HC A06/MF A01 CSCL 20D

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COMPUTER PROGRAM GRADE II FOR THE

DES..'' AND ANALYSIS OF HEAT-PIPE WICKS

November 1976

Prepared by

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Prepared for

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COMPUTER PROGRAM GRADE II
FOR THE DESIGN AND ANALYSIS OF HEAT-PIPE WICKS

1.0 INTRODUCTION

This user's manual describes the revised version of the computer program GRADE[1], which designs and analyzes heat pipes with graded-porosity fibrous slab wicks. The revisions, which are based on work done under contract NAS 2-8310 with NASA Ames Research Center and reported in Reference (2), were incorporated so that the mathematical model more completely describes an actual graded-porosity-wick heat pipe. In particular, GRADE II now includes:

- Automatic calculation of the minimum condenser-end stress that will not result in an excess-liquid puddle or a liquid slug in the vapor space,
- Numerical solution of the equations describing flow in the circumferential grooves to assess the burnout criterion,
- Calculation of the contribution of excess liquid in fillets and puddles to the heat-transport,
- Calculation of the effect of partial saturation on the wick performance,
- Calculation of the effect of vapor flow, which includes viscous-inertial interactions.

In addition to these extended capabilities, the new version retains the capabilities of the original program:

- Calculation of the optimum porosity variation and the corresponding maximum heat-transport rate,
- Calculation of the maximum heat-transport rate at other than the wick's design condition (different temperature, elevations, gravitational field, etc.),
- Calculation of the maximum heat-transport rate for a specified porosity distribution, which includes a uniform-porosity wick,

- The heat pipe can have multiple sections each having different tilts,
- Multiple heat input and output zones,
- Calculation of the total fluid charge.

The theoretical basis for GRADE II is described in Section 2.0 and the instructions for preparing the input are given in Section 3.0. If excess-liquid effects are to be included in the calculations, a separate program FILLET must be run, whose output is a binary file that becomes additional input for GRADE II. This program is described in Section 4.0. Two sample programs are described in Section 5.0. The Appendix contains descriptions and listings of GRADE II and FILLET.

2.0 THEORETICAL BASIS FOR GRADE II

This section describes the application of fundamental theoretical and experimental results for capillary flow through fibrous media previously reported in Reference (3) and (4) to the optimum design of heat-pipe wicks. To be specific, we consider a heat pipe, as depicted in Figure 1, with a fibrous slab wick for the axial transport of liquid and circumferential grooves for the transport across the evaporation and condensation surfaces. The slab wick is ultimately limited in heat-transport capacity because the factors that affect its performance, the capillary-pressure limit and the permeability, are related inversely. Any change in the wick structure that increases its capillary-pressure limit decreases its permeability and vice versa. The simple uniform-porosity wick is optimized by selecting the fiber diameter and porosity that maximizes its heat transport. Such a wick, however, has an unnecessarily low permeability, everywhere along its length except where it begins to dry out under maximum load. A further capacity increase is possible if one considers a wick whose porosity varies along its length. With a graded-porosity wick, the porosity is optimally varied such that at every axial location it is only as low as required to ensure the wick remains nearly saturated. Thus, the permeability is everywhere as high as possible. The potential increase in capacity over a uniform porosity wick depends on the particular applications, but it is often greater than a factor of two.

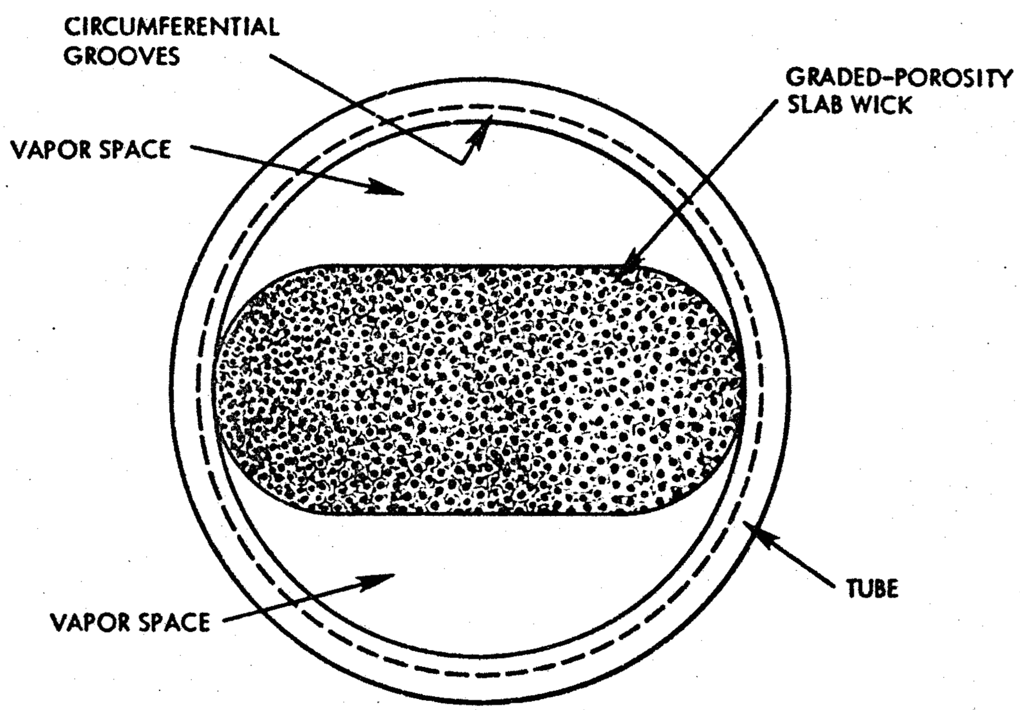

Figure 1. Cross-Section of a Fibrous-Slab-Wick Heat Pipe

2.1 PROPERTIES OF A FIBROUS WICK

We first summarize the results of Reference (3) and (4) for capillary flow through porous media and then derive the relationships that are required for the design of a wick. Expressions for the capillary-pressure limit P_c and the permeability K_o for a wick of uniform porosity ϵ consisting of a three-dimensional random distribution of fibers of diameter δ were shown to be

$$P_c = 3.2465\ H(\sigma/\delta)(1 - \epsilon)/\epsilon \tag{1}$$

and

$$K_o = (3/8)\delta^2\ [\epsilon/(1 - \epsilon)]/ \left\{ \frac{4\epsilon}{4(1 - \epsilon) - (1 - \epsilon)^2 - 2\ln(1 - \epsilon) - 3} - \frac{8}{\ln(1 - \epsilon) + [1 - (1 - \epsilon)^2]/[1 + (1 - \epsilon)^2]} \right\} \tag{2}$$

where σ is the surface tension and H is the hysteresis constant that is unity if the liquid front is advancing in the wick and an empirically found value of 1.955 if it is receding. Actually, the wick does not empty abruptly when the capillary-pressure limit is exceeded, but rather it progressively desaturates. The wick is envisioned as consisting of local regions having porosities that are normally distributed with a mean value ϵ_o and a standard deviation σ_d. The fraction of the wick with a porosity that lies between ϵ and $\epsilon + d\epsilon$ is given by

$$f(\epsilon, \epsilon_o, \sigma_d) = \frac{1}{\sqrt{2\pi}\ \sigma_d}\ e^{-(\epsilon - \epsilon_o)^2/2\sigma_d^2} \tag{3}$$

The standard deviation was found experimentally to correlate with the mean porosity by the expression

$$\sigma_d = 0.22(1 - \epsilon_o) \tag{4}$$

When the wick is subject to a vapor-liquid pressure difference P, which we call the capillary stress, a local region is filled with liquid if its porosity is sufficiently low that the capillary-pressure limit given by Eq. (1) exceeds the capillary stress. The saturation fraction,

which is the ratio of the liquid content of the wick to the content when it is completely saturated, was shown to be

$$S = F[(\varepsilon^* - \varepsilon_o)/\sigma_d] - (\sigma_d/\varepsilon_o)f[(\varepsilon^* - \varepsilon_o)/\sigma_d] \tag{5}$$

where f(z) is the standardized normal distribution and F(z) is the standardized cumulative distribution, and ε^* is the critical value of the local porosity for which the capillary pressure limit equals the capillary stress. Its value, obtained from Eq. (1), is

$$\varepsilon^* = \left(1 + \frac{P\delta/\sigma}{3.465\ H}\right)^{-1} \tag{6}$$

To obtain an expression for the permeability of the partially saturated wick, Eq. (2) is applied to those regions with a porosity below the critical value. The resulting expression is

$$K(\varepsilon_o, \varepsilon^*, \delta, \sigma_d) = \int_0^{\varepsilon^*} K_o(\delta, \varepsilon) f(\varepsilon, \varepsilon_o, \sigma_d) d\varepsilon \tag{7}$$

To this point, we have summarized the results of Reference (3) and (4). We now calculate the mean porosity that maximizes the permeability for a prescribed capillary stress. If the porosity is too high, the wick is unable to hold liquid at the prescribed stress which results in a low permeability. If, on the other hand, the porosity is too low, the wick will remain nearly saturated, but the fibers are unnecessarily close together which also results in a low permeability. Equation (7) is the basis for the optimization. A specified value of the capillary stress fixes ε^* by way of Eq. (6). The dependence of the permeability on the fiber diameter δ is eliminated from Eq. (7) by using δ^2 to nondimensionalize K, and the dependence on δ_d is eliminated with Eq. (4). The resulting expression for the dimensionless permeability $\overline{K} = K/\delta^2$ is

$$\overline{K}(\varepsilon_o, \varepsilon^*) = \int_0^{\varepsilon^*} \frac{3}{8} \frac{\varepsilon}{1 - \varepsilon} \left(\frac{4\varepsilon}{4(1 - \varepsilon) - (1 - \varepsilon)^2 - 2\ln(1 - \varepsilon)} - \frac{8}{\ln(1 - \varepsilon) + \dfrac{1 - (1 - \varepsilon)^2}{1 + (1 - \varepsilon)^2}} \right)^{-1} \frac{1.8}{1 - \varepsilon_o} e^{-\dfrac{10.3(\varepsilon - \varepsilon_o)^2}{(1 - \varepsilon_o)^2}} d\varepsilon \tag{8}$$

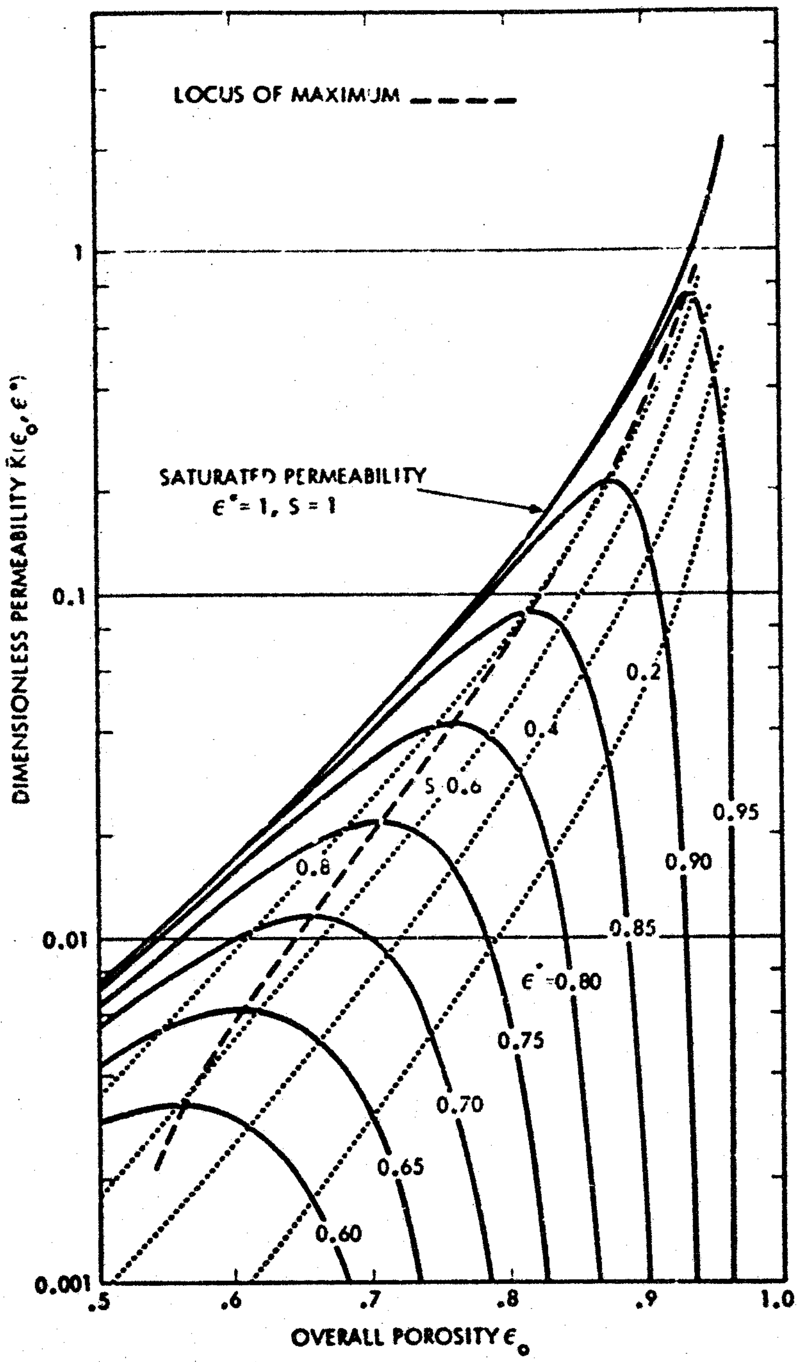

Figure 2. Dimensionless Permeability K = K/δ^2 of a Partially Saturated Wick

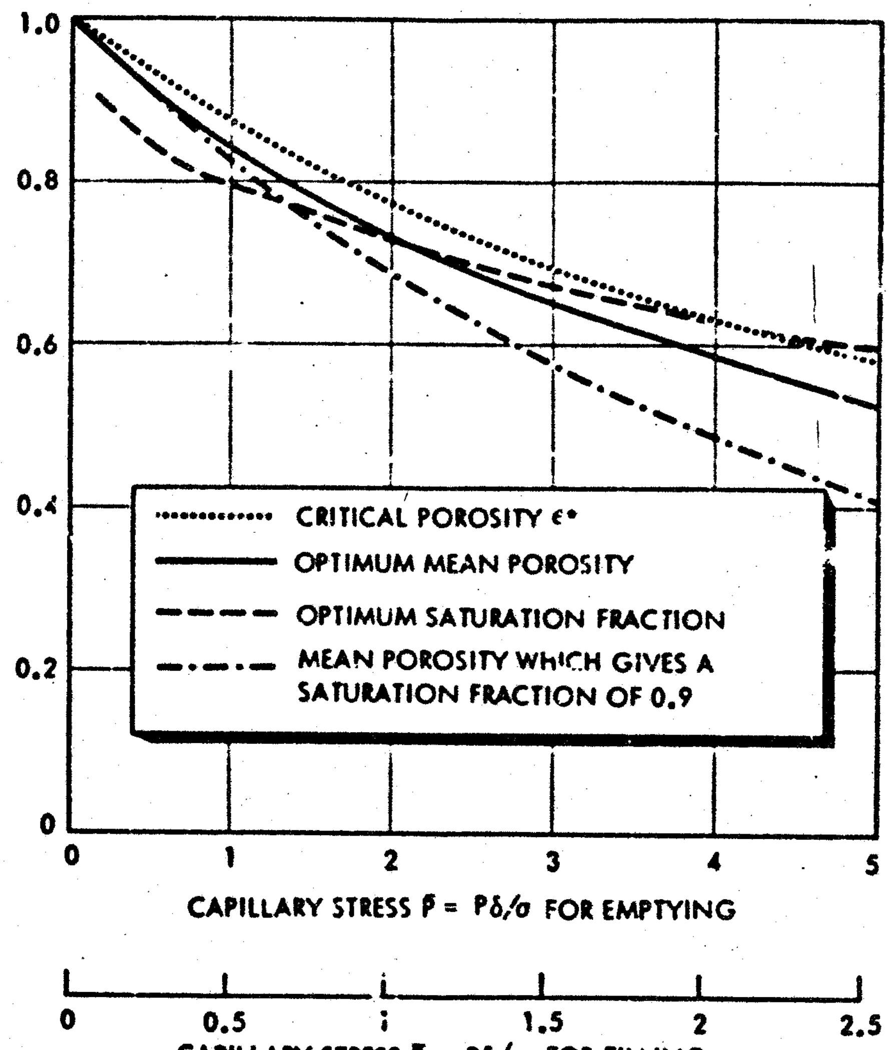

Figure 3. Key Relationships for Design of a Graded-Porosity Wick

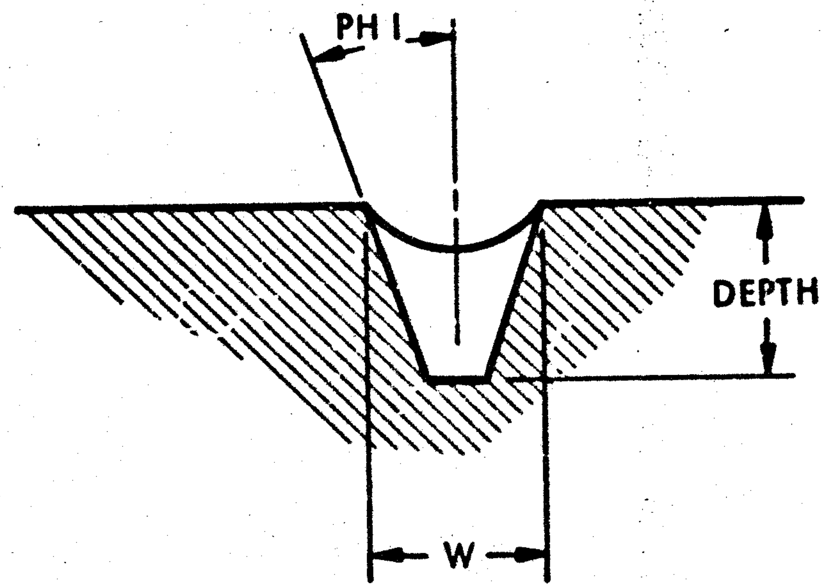

Figure 4. Cross-Sectional Geometry of a Circumferential Groove

This integral was evaluated numerically with Simpson's rule on a computer. The results are shown in Figure 2. Also shown are lines of constant saturation fraction, which were calculated from Eq. (5) with σ_d given by Eq. (4), and the locus of points for which the permeability is maximum.

Figure 3 relates the critical porosity ε^* to the dimensionless capillary stress $P\,\varepsilon/\varepsilon$ and displays the optimum mean porosity and the corresponding saturation fraction as a function of the stress. A graded-porosity wick ideally would have a porosity variation that follows the optimum-porosity curve as the capillary stress builds from a low value at the end of the condenser to a high value at the end of the evaporator. The optimum saturation fraction would range from a value above 0.8 at a low stress typical of the condenser region to a value below 0.7 at a high stress typical of the evaporator region. The fact that such a wick operates with a liquid fill well below that required to saturate it presents practical problems. If, for example, a fluid charge is used that is sufficient to completely saturate the wick, then at the maximum heat-transport rate liquid will be given up that could result in flooding of the condenser. If, on the other hand, a fluid charge is used that is just sufficient to provide the optimum saturation fraction at the maximum heat-transport rate, then there is no guarantee that the liquid will be properly distributed along the wick. To avoid these problems, the wicks are designed with a porosity variation that provides a uniform high-level of saturation. Thus, instead of operating along the peaks of the partially saturated permeability curves of Figure 2, the wick is designed to operate to the left of the peaks along a line of constant saturation fraction. Equation (5) is used to obtain the expression for the porosity that provides the desired saturation fraction. The equation is transcendental in ε_0, and it must be solved iteratively. For high levels of saturation, however, the second term of Eq. (5) is small compared to the first, and an accurate approximation for ε_0 can be obtained by neglecting it, which results in

$$\varepsilon_0 = \frac{\varepsilon^* - F^{-1}(S)/4.5}{1 - F^{-1}(S)/4.5} \qquad (9)$$

where we have used Eq. (4) to eliminate σ_d. Equation (9) was used to calculate the curve of Figure 3 which gives the porosity as a function of capillary stress that provides a saturation fraction of 0.9. [The criti-

cal porosity is first calculated as a function of stress from Eq. (6)].

2.2 DESIGN OF A WICK

We now focus attention on the hydrodynamic optimization of a heat pipe for maximum heat transport in a given application. One must be alert, however, to the possibility that other limiting factors may come into play before the hydrodynamic wicking limit is reached. Such factors are, for example, the heat-flux limit due to boiling in the wick, and the sonic vapor-flow limit. The procedure described herein is used to calculate the optimum wick porosity variation for a fixed heat-pipe geometry. For the heat-pipe diameter considered, a change in wick area may further increase the capacity. If the capillary stress is due primarily to liquid flow through the wick, an increase in wick area will increase the capacity. If, on the other hand, the stress is due primarily to vapor-flow pressure drop, or if there is a relatively large vapor-space capillary back pressure, which we will see presently can adversely affect the porosity variation, a reduction in wick area will increase the capacity. In fact, for a given heat-pipe diameter, there is always an optimum wick area.

The key equation describing the heat-pipe hydrodynamics governs the axial variation of the capillary stress. In a gravitational field, however, it varies hydrostatically across the heat pipe as well; so to have a unique value at every axial location, we take its value at the top of the wick. The equation governing the rate of increase of stress P with axial distance x from the condenser end is

$$\frac{dP}{dx} = \frac{\nu_\ell \, \dot{m}(x)}{K(\epsilon_0, \epsilon^*)A_w} + (\rho_\ell - \rho_v)\, g \, \frac{dh}{dx} +$$

$$\frac{\overline{K}}{Re} \; \frac{\rho_v \overline{U}^2}{2D} - F_s \frac{d}{dx} (\rho_v \overline{U}^2) \tag{10}$$

The first term on the right of the equal sign gives thre stress increase due to liquid of kinematic viscosity ν_ℓ flowing through a wick of cross-sectional area A_w at a mass rate $\dot{m}(x)$. The permeability K depends on the local porosity ϵ_0 and on the capillary stress through the critical porosity ϵ^*.

The second term gives the change in hydrostatic pressure in the liquid of density ρ_ℓ due to changes of heat-pipe elevation h(x) measured from a horizontal reference plane to the top of the wick.

The third and fourth terms are due to vapor flow, as discussed in Reference (2). Here $\overline{U}$ is the average velocity in the vapor space, R_e is the Reynolds number, and D is the hydraulic diameter of the vapor space. The third term is due to viscous shear on the walls, and the fourth is due to inertial effects. $\overline{K}$ and F_s are, respectively, an average friction-factor coefficient and shape factor, which are calculated according to Reference (2) to give the proper balance between inertial and viscous effects. The mass flow rate is related to the latent heat of vaporization h_{fg} and the heat input per unit length Q(x) (assumed negative in regions of condensation) by

$$\dot{m}(x) = -\,(1/h_{fg}) \int_0^x Q(x)\,dx \tag{11}$$

The optimum porosity distribution is calcualted by numerically integrating Eq. (1) with an assumed value for the heat load. At each step of the integration, the critical porosity ε^* and the wick porosity ε_0 are calculated from Eqs. (6) and (9) with a specified high level of saturation fraction S and with the hysteresis constant H = 1.955 for liquid on the verge of emptying. Because of hysteresis, however, the calculated porosity ε_0 may be too high for the wick to self-fill to the specified level of saturation under a zero heat load. Therefore, Eqs. (6) and (9) are used again with H = 1 for liquid filling the wick and the stress given by integration of Eq. (10) with $\dot{m}(x) = 0$ to calculate ε^* and ε_0 for the wick to fill. These latter values are used if the porosity required to fill the wick under zero load is lower than the porosity required to sustain the stress under the assumed load.

Once ε_0 and ε^* have been determined, the value of the permeability at the particular integration step is calculated from Eq. (8). In regions of evaporation, the circumferential grooves are checked at each step to see whether or not they dry up. The subroutine DRY, which is based on the mathematical model of Reference (2), is called to make this check. It takes into account viscous flow in the groove under the action of surface tension and gravity. If the grooves are found to dry up,

the integration is stopped, the assumed heat load is reduced, and the integration is repeated. If the integration continues to the evaporator end of the heat pipe without groove dry-up occurring, the assumed heat load is increased, and the integration is repeated. A binary search is used to find the maximum heat load that does not result in groove dry-up.

The calculation of the condenser-end stress used to begin the integration is crucial. The stress must be high enough to prevent a liquid puddle or slug from forming in the lowest vapor space. If, however, the stress is set too high, the wick must begin with an unnecessarily low porosity to enable the wick to fill. In the condenser region, where the wick porosity is relatively high, a small reduction in porosity can result in a large reduction in permeability. For example, if a saturation fraction of 0.9 is specified, then we see from Figure 2 that a 1 percent reduction in a typical condenser-end porosity of 0.88 leads to a 15 percent reduction in the permeability. Therefore, for a high heat-transport capacity, the condenser-end stress should be kept as low as possible. This is one reason why, as discussed previously, a reduction in wick area can result in an increase in capacity. The increased size of the vapor space reduces its capillary back pressure and allows a higher condenser-end porosity.

The first requirement on the condenser-end stress is that it must be high enough that a puddle does not form in the lower vapor space. For simplicity, we restrict our attention to the situation depicted in Figure 1 where the slab wick is horizontal. If the capillary stress at the top of the wick has been increased to a point where a puddle is just about to disappear, the radius of curvature of the meniscus of the puddle is nearly equal to the tube radius R. The stress σ/R at the puddle surface is related hydrostatically to the stress at the top of the wick; thus the stress required to prevent a puddle is

$$P_0 = \sigma/R + (\rho_\ell - \rho_V)\, g\, h_W \tag{12}$$

where h_W is the distance between the top of the wick and the bottom of the tube. The second requirement on the condenser-end stress is that it should be high enough to prevent a liquid slug in the lower vapor space.

The conditions under which a slug will form, presented in Reference (2), are calculated by subroutine VSBKS. The stress used to begin the integration is the greater of the value for the formation of a puddle and a liquid slug.

3.0 INPUT FOR GRADE II

The input is in Fortran NAMELIST form. The required parameters are defined and discussed below. An input form is given in Table 1.

3.1 HEADINGS

After writing on the first card or line the NAMELIST identifier $GRDATA, the user then inputs two lines of descriptive information by writing on one card or line HD1 = 60H followed by up to 60 characters of title and on the next card or line HD2 = 60H followed by another 60 characters. GRADE II will print these two lines at the beginning of the output.

3.2 FLUID PROPERTIES

GRADE II automatically computes the required fluid properties for one of several fluids, which the user specifies by selecting a value of LIQ from the following list:

	Fluid	Temperature Range
LIQ = 1	Water	(0C < T < 204C)
LIQ = 2	Ammonia	(-78C < T < 88C)
LIQ = 3	Methyl Alcohol	(-96C < T < 193C)
LIQ = 4	FREON-21	(-48C < T < 152C)
LIQ = 5	Ethane	(-93C < T < 27C)
LIQ = 6	Methane	(-173C < T < -84C)
LIQ = 7	Nitrogen	(-207C < T < -157C)

The properties are for a temperature TKELVN that the user inputs in degrees Kelvin. All other fluid properties are automatically computed for that temperature. If another fluid is used, set LIQ = 0. Then, values must be specified for the following quantities:

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Date

Name

Problem No.

No. of Cards

TABLE I

NAMELIST INPUT FORM

1

Page 1 of

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Verified by

TITLE: GRADE II INPUT

80 COMMENT

```
$ GRDATA
HD1 = 60H
HD2 = 60H
LIQ =
TKELVN=
RHOL =
RHOV=
VISL =
VISV =
ST =
HFG=
HPID=
WKTH=
IOEØM=
NQ=
XQ=
FQ=
QDØT=
NELEV=
XELEV=
ELEV=
GEE=
GRVS=
W=
```

Input only if LIQ = 0

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Name ______

TABLE I

Problem No ______ NAMELIST INPUT FORM Keypunched by

No. of Cards 1 Verified by

TITLE: GRADE II INPUT (CONT'D) 80 COMMENTS

DEPTH=
PHI=
ANGWET=
DIAF=
S=
EPSMIN=
LASTEPS=
NEPS=
XEPS=
EPSX=
DX=
ISLFPRM=
ROUGH=
IFLTS=
NCASE=
$END
$GRDATA

For another case, input only parameters that are changed

NL $END

SYSTEMS 2994 REV. 6-73

Quantity	Symbol	Units
Liquid density	RHOL	Kg/cu. m
Vapor density	RHOV	Kg/cu. m
Liquid viscosity	VISL	N·s/sq. m
Vapor viscosity	VISV	N·S/sq. m
Surface tension	ST	N/m
Latent heat	HFG	J/Kg

3.3 GEOMETRICAL PARAMETERS OF THE HEAT-PIPE CROSS SECTION

As shown in Figure 1, the heat pipe uses a slab wick in either a horizontal or vertical orientation. The input parameters that specify the cross-sectional geometry are:

Quantity	Symbol	Units
Tube inside diameter	HPID	cm
Slab-wick thickness	WKTH	cm
Geometrical parameter:		
Horizontal slab wick	IGEOM = 0	
Vertical slab wick	IGEOM = 1	

All other parameters of the heat-pipe cross section, such as the wick area, vapor-space hydraulic diameter, etc. are automatically calculated.

3.4 HEAT INPUT

The user specifies the heat-input distribution by specifying the fraction of the total heat-transfer rate for up to ten segments of the heat pipe. Heat transfer is assumed to be constant along the given segment. Values for the following parameters are required:

NQ - The number of segments, which must not exceed ten, into which the heat pipe is divided.

XQ(I) - The length of the I^{th} segment in cm. The segments must be numbered consecutively along the heat pipe beginning at the condenser end.

FQ(I) - The fraction of the total heat-transfer rate entering the I^{th} segment. If the I^{th} segment is a condenser, FQ(I) is negative. If the I^{th} segment is adiabatic, FQ(I) is zero.

QDOT - A nominal heat-transfer rate in watts, which is the user's best guess at the maximum. A close guess reduces the number of iterations to the final answer.

3.5 ELEVATIONS

The user specifies the heat-pipe orientation in a gravitational field by inputing values for elevations of points along the heat pipe where the slope changes. Between points, GRADE assumes a linear variation of elevation. Values of the following parameters are required (except for zero gravity):

NELEV - The total number of points along the heat pipe, which must not exceed 10.

XELEV(I) The distance along the heat pipe in cm to the Ith point. Both ends of the heat pipe must be input, therefore the first point must be at zero distance [XELEV(1) = 0.0], and the last at the total heat-pipe length [XELEV(NELEV) = L].

ELEV(I) - The elevation in cm of the Ith point relative to a horizontal reference plane.

GEE - Gravitational acceleration in standard gravities.

3.6 CIRCUMFERENTIAL GROOVE PARAMETERS

The cross-section of the circumferential grooves is trapezoidal as shown in Figure 4.

The following parameters must be input:

Quantity	Symbol	Units
Number of grooves per cm	GRVS	cm^{-1}
Groove opening	W	cm
Groove depth	DEPTH	cm
Groove half angle	PHI	degrees
Wetting angle	ANGWET	degrees

3.7 WICK PARAMETERS

The user can use the program either to design an optimum graded-porosity wick and compute its capacity, or he can use it to compute the capacity of a wick with a specified porosity distribution.

3.7.1 Design of a Graded-Porosity Wick

To design a graded-porosity wick, the user must specify:

Quantity	Symbol	Units
Fiber diameter	DIAF	cm
Saturation fraction	S	
Minimum allowable porosity	EPSMIN	

The saturation fractions are the uniform high level of saturation that the wick is to maintain. We have been using S = 0.9. When the porosity variation is to be designed, the parameters LASTEPS and NEPS must be set to zero or, equivalently, just not included in the NAMELIST. The minimum porosity EPSMIN is set so that a wick will not be designed that is too dense to manufacture.

3.7.2 Capacity at Off-Optimum Operation

The program is set up to run several cases; one NAMELIST input is simply followed by another. When a wick is designed and the user desires to calculate the performance of that wick at off-optimum conditions (a different temperature or evaporator elevation, for example), he simply sets the parameter LASTEPS = 1. This causes the porosity variation to be that of the previous case (be sure to set NEPS = 0).

3.7.3 Specified Porosity Distribution

If the user desires to compute the capacity of a wick with a specified porosity distribution, he specifies the local porosity of a number of points along its length. Between points, values of the porosity are calculated by linear interpolation. The required input parameters are:

Quantity	Symbol	Units
Number of porosity points (up to 10)	NEPS	
Distance to I^{th} point	XEPS(I)	cm
Porosity of I^{th} point	EPSX(I)	
Wick fiber diameter	DIAF	cm

The first point must be at the condenser end [XEPS(1) = 0] and the last point must be at the evaporator end [XEPS(NPHI) = heat-pipe length]. Set S = 0 and LASTEPS = 0.

3.8 OTHER INPUT PARAMETERS

DX - The integration step size in cm.

IPRIMED - Equals 0 if the user requires the wick to self-prime under no load at the operating elevations.
- Equals 1 if the wick is allowed to self-prime level under no load before the heat pipe is raised to the operating elevations.

ROUGH - The average surface roughness of the vapor spaces, which is used for the calculation of the turbulent friction-factor coefficient.

IFLTS - Equals 1 if the contribution of excess-liquid fillets and puddles are to be included, in which case an additional input file is needed (see Section 4).
- Equals 0 if the excess-liquid contribution is not to be included.

NCASE - Equals 1 if a NAMELIST input for another case is to follow, which is exactly like the first except only those parameters that are to be different in the new case are included.
- Equals 0 if the present case is the last case.

$END - Ends present NAMELIST input.

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TABLE II

NAMELIST INPUT FORM

1

Page 1 of 1

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TITLE: FILLET INPUT

COMMENTS

```
$ FILLETD
LIQ =
TKELVN =
RHO =
ST =
IGECM =
WKTH =
HPID =
SEE =
$ END
```

Input only if LIQ = 0

NL

4.0 THE PROGRAM FILLET

If the user includes the effect of excess-liquid fillets and puddles, he sets IFLTS = 1 in the NAMELIST input for GRADE II. This causes GRADE II to read data from a binary file, TAPE 7, which is the output of the program FILLET. The theoretical basis for FILLET is described in Reference (2). In essence, it numerically integrates the differential equations that describe the free-surface shape of fillets and puddles that can exist in the heat pipe. The output from FILLET is a table of total cross-sectional area and hydraulic diameter of the excess liquid as a function of stress.

4.1 INPUT TO FILLET

FILLET also uses NAMELIST input. An input form is given in Table II. The NAMELIST identifier is $FILLETD. The input variable, which have the same definitions as those for GRADE II are:

LIQ TKELVN RHO* ST*	Refer to Section 3.2
IGEOM WKTH HPID	Refer to Section 3.3
GEE	Refer to Section 3.5

*RHO, which is the difference between the liquid and and vapor density (RHOL-RHOV), and the surface tension ST are input only if LIQ = 0.

The NAMELIST ends with the line $END.

5.0 SAMPLE CALCULATIONS

In this section we describe two sample problems. The first is selected to illustrate the option for including excess liquid, while the second is selected to illustrate the design of a graded-porosity wick.

5.1 A SIMPLE METAL-FELT SLAB-WICK HEAT PIPE

The input file for the first heat pipe we are considering is given in Table III. The heat pipe is 30-cm long, with condenser, adiabatic and evaporator lengths of 10 cm each (XQ = 3* 10.). The inside diameter of the tube is 1. cm (HPID = 1.), the wick thickness is .4 cm (WKTH = .4) and it is vertical (IGEOM = 1). The wick is a slab of felt metal which has a fiber diameter of 0.002 cm (DIAF = .002). To specify a uniform porosity, we specify the porosity of two points (NEPS = 2) at the condenser end and the evaporator end (XEPS = 0., 30.). At each point we set the porosity to 0.80 (EPSX = 2* .80), and thus a linear interpolation for points in between results in the desired uniform porosity. The circumferential grooves have a width at the top of 0.015 cm (W = .015), a depth of 0.015 cm (DEPTH = .015) and a half angle of 20 degrees (PHI = 20.). We specified 100 grooves per cm (GRVS = 100.). Upon reflection one sees that it would be impossible to cut such grooves so close together; however, they will serve for purposes of this illustration. Several cases are run with the evaporator elevated 2., 0., 4., and 6. cm higher than the condenser end. The fluid is ammonia (LIQ = 2) at 300K (TKELVN = 300.).

Since the effect of liquid fillets are to be included, IFLTS is set equal to unity, and the program FILLET must be run first. The NAMELIST input to FILLET is shown in Table IV. The output from FILLET is written in binary on TAPE 7, which is read by GRADE II along with the input of Table III.

The output from GRADE II is shown for the first case (evaporator elevation of 2. cm) in Table V. First the input parameters and calculated parameters are listed. Most of the calculated parameters are clearly explained by their name, i.e., wick area, etc. We will comment on those that require elaboration:

TABLE III

SAMPLE INPUT TO GRADE II

```
$GRDATA
HD1=60H1SIMPLE FELT-METAL SLAB-WICK HEAT PIPE
HD2=60H FILE NAME  X13        9/20/76
LIQ=2
THELVN=300.
HPID=1.
WKTH=.4
IGEOP=1
NG=3
XG=3*10.
FQ=-1.,0.,1.
QDOT=100.
NELEV=2
XELEV=0.,30.
ELEV=0.,2.
GEE=1.
GRVS=100.
W=.019
DEPTH=.019
PHI=20.
ANGWET=0.
DIAF=.002
NEPS=2
XEPS=0.,30.
EPSX=2*.8
DX=1.
IPRIMED=1
ROUGH=.02
IPLTS=1
NCASE=1
$END
$GRDATA
ELEV=0.,0.
$END
$GRDATA
ELEV=0.,4.
$END
$GRDATA
ELEV=0.,6.
NCASE=0
$END
```


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TABLE IV. SAMPLE INPUT TO FILLET

FOR SIMPLE FELT-METAL SLAB-WICK HEAT PIPE

```
$FILLETD
LIQ=2
TKELVN=300.
IGEOM=1
WKTH=.4
HPID=1.
GEE=1.
$END
```

TABLE V - OUTPUT FROM GRADE II

1SIMPLE FELT-METAL SLAB-WICK HEAT PIPE
FILE NAME X13 9/20/76

INPUT VARIABLES AND FLUID PROPERTIES:

LIQUID NUMBER..................	LIQ =	2	
TEMPERATURE....................	TKELVN =	3.00000E+02	DEGREES KELVIN
LIQUID DENSITY.................	RHOL =	6.00409E+02	KG/CU. M
VAPOR DENSITY..................	RHOV =	6.26329E+00	KG/CU. M
SURFACE TENSION................	ST =	1.95290E-02	NEWTONS/M
LIQUID VISCOSITY...............	VISL =	1.30130E-04	NEWTON-SEC/SQ. M
VAPOR VISCOSITY................	VISV =	9.99266E-06	NEWTON-SEC/SQ. M
LATENT HEAT....................	HFG =	1.16066E+06	JOULES/KG
VAPOR PRESSURE.................	PV =	1.06096E+06	N/SQ. M
THERMAL CONDUCTIVITY OF LIQ....	XKL =	5.09329E-01	WATTS/M K
SPECIFIC HEAT RATIO............	SHRV =	1.31000E+00	
MOLECULAR WEIGHT...............	XMW =	1.70320E+01	
FREEZING TEMPERATURE...........	TF =	1.95444E+02	DEGREES KELVIN
GRAVITATIONAL ACCELERATION.....	GEE =	1.00000E+00	STANDARD GRAVITIES
HEAT-PIPE GEOMETRY.............	IGEOM =	1	
(0=HORIZ. SLAB, 1=VERT. SLAB, 3=GENERAL)			
HEAT-PIPE INSIDE DIAMETER......	HPID =	1.00000E+00	CM
WICK THICKNESS.................	WKTH =	4.00000E-01	CM
WICK AREA......................	AW =	3.89061E-01	SQ. CM
WICK HEIGHT....................	HW =	9.58259E-01	CM
WICK FIBER DIAMETER............	DIAF =	2.00000E-03	CM
SPECIFIED SATURATION FRACTION..	S =	0.	
MINIMUM ALLOWABLE POROSITY.....	EPSMIN =	0.	
NO. SPECIFIED-POROSITY PTS.....	NEPS =	2	
POROSITY POINT NO. 1			
DISTANCE TO POINT........	XEPS =	0.	CM
POROSITY AT POINT........	EPSX =	[illegible].00000E-01	
POROSITY POINT NO. 2			
DISTANCE TO POINT........	XEPS =	3.00000E+01	CM
POROSITY AT POINT........	EPSX =	[illegible].00000E-01	

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```
NO. OF EQUAL VAPOR SPACES......       NVS =  2
AREA OF EACH VAPOR SPACE......        AVS =  1.98168E-01  SQ. CM
VAPOR-SPACE DIAMETER..........      DIAVS =  3.81665E-01  CM
HEIGHT TO TOP OF LOWEST V.S. .        HVS =  9.16515E-01  CM
TOTAL ACTIVE PERIMETER OF V.S.      PERIM =  1.15928E+00  CM

GROOVE OPENING................          W =  1.50000E-02  CM
GROOVE DEPTH..................      DEPTH =  1.50000E-02  CM
GROOVE HALF-ANGLE.............        PHI =  2.00000E+01  DEGREES
WETTING ANGLE.................     ANGWET =  0.           DEGREES
FIRST GROOVE FEED LOCATION....        TH1 = -1.56422E+02  DEGREES FROM TOP
SECOND GROOVE FEED LOCATION...        TH2 = -2.35782E+01  DEGREES FROM TOP
RADIAL INPUT FRACTION.........      FCGRV =  5.00000E-01
WICK HEIGHT REL. TO TUBE AXIS.       HREF =  5.00000E-01  CM
NO. GROOVES PER CM............       GRVS =  1.00000E+02  /CM

NOMINAL HEAT-TRANSFER RATE....       QDOT =  1.00000E+02  WATTS
NO. HEAT-INPUT SECTIONS.......         NC =  3
SECTION NUMBER   1
     SECTION LENGTH...........         XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......         FC = -1.00000E+00
SECTION NUMBER   2
     SECTION LENGTH...........         XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......         FC =  0.
SECTION NUMBER   3
     SECTION LENGTH...........         XC =  1.00000E+01  CM
     HEAT-INPUT FRACTION......         FC =  1.00000E+00

NO. ELEVATION POINTS..........      NELEV =  2
ELEVATION POINT NO.   1
     DISTANCE TO POINT........      XELEV =  0.           CM
     ELEVATION OF POINT.......       ELEV =  0.           CM
ELEVATION POINT NO.   2
     DISTANCE TO POINT........      XELEV =  3.00000E+01  CM
     ELEVATION OF POINT.......       ELEV =  2.00000E+00  CM

INTEGRATION STEP SIZE.........         DX =  1.00000E+00  CM

WICK PRIMED LEVEL (1=YES).....     IPRIMD =  1

LIQUID FILLETS ALONG WICK.....      IFLTS =  1
```

```
ANOTHER CASE (0=NO, 1=YES)....    NCASE =  1
USE LAST POROSITY DISTN.......  LASTEPS =  0
ONLY ONE INTEGRATION PASS.....    IPASS =  0
PLOT POROSITY.................    IPLOT =  0
VAPOR SPACE SURFACE ROUGHNESS.    RCUGH =  2.00000E-02  CM
```

FINAL SOLUTION

```
THE MAXIMUM HEAT-TRANSFER RATE IS.......  3.13477E+01  WATTS
THE TOTAL LIQUID IN WICK IS.............  5.69332E+00  GRAMS
THE VAPOR REYNOLDS NUMBER IS............  2.60414E+02
THE MAX. VAPOR VELOCITY HEAD IS.........  4.84206E-04  CM LIQ.
THE RADIAL REYNOLDS NUMBERS ARE:
     FOR SECTION NO.  1................ -2.22577E+00
     FOR SECTION NO.  2................  0.
     FOR SECTION NO.  3................  2.22577E+00
```

DISTANCE (CM)	STRESS (CM LIQ.)	STATIC HEAD (CM LIQ.)	POROSITY	SATURATION	VAPOR PRESSURE (CM LIQ.)
0.	1.0256E+00	0.	8.0000E-01	0.	0.
1.0000E+00	1.0924E+00	6.6667E-02	8.0000E-01	9.9998E-01	1.1267E-05
2.0000E+00	1.1605E+00	1.3333E-01	8.0000E-01	9.9998E-01	4.4624E-05
3.0000E+00	1.2321E+00	2.0000E-01	8.0000E-01	9.9998E-01	1.0036E-04
4.0000E+00	1.3124E+00	2.6667E-01	8.0000E-01	9.9998E-01	1.7931E-04
5.0000E+00	1.4137E+00	3.3333E-01	8.0000E-01	9.9998E-01	2.8018E-04
6.0000E+00	1.5584E+00	4.0000E-01	8.0000E-01	9.9998E-01	4.0346E-04
7.0000E+00	1.7755E+00	4.6667E-01	8.0000E-01	9.9998E-01	5.4915E-04
8.0000E+00	2.0516E+00	5.3333E-01	8.0000E-01	9.9998E-01	7.1726E-04
9.0000E+00	2.3754E+00	6.0000E-01	8.0000E-01	9.9998E-01	9.0778E-04
1.0000E+01	2.7383E+00	6.6667E-01	8.0000E-01	9.9997E-01	1.1337E-03
1.1000E+01	3.1164E+00	7.3333E-01	8.0000E-01	9.9996E-01	1.4305E-03
1.2000E+01	3.4957E+00	8.0000E-01	8.0000E-01	9.9995E-01	1.7274E-03
1.3000E+01	3.8762E+00	8.6667E-01	8.0000E-01	9.9993E-01	2.0245E-03
1.4000E+01	4.2577E+00	9.3333E-01	8.0000E-01	9.9991E-01	2.3211E-03
1.5000E+01	4.6395E+00	1.0000E+00	8.0000E-01	9.9989E-01	2.6160E-03
1.6000E+01	5.0215E+00	1.0667E+00	8.0000E-01	9.9986E-01	2.9146E-03
1.7000E+01	5.4040E+00	1.1333E+00	8.0000E-01	9.9982E-01	3.2117E-03
1.8000E+01	5.7867E+00	1.2000E+00	8.0000E-01	9.9977E-01	3.5095E-03
1.9000E+01	[illegible]	1.2667E+00	8.0000E-01	9.9971E-01	3.8054E-03
2.0000E+01	6.5531E+00	1.3333E+00	8.0000E-01	[illegible]	4.1023E-03
2.1000E+01	[illegible]	1.4000E+00	8.0000E-01	[illegible]	[illegible]
2.2000E+01	[illegible]	1.4667E+00	8.0000E-01	9.9944E-01	4.6911E-03
2.3000E+01	[illegible]	1.5333E+00	8.0000E-01	9.9933E-01	[illegible]

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2.4000E+01	7.8528E+00	1.6000E+00	8.0000E-01	9.9922E-01	5.7093E-03
2.5000E+01	8.0974E+00	1.6667E+00	8.0000E-01	9.9911E-01	5.9914E-03
2.6000E+01	8.3096E+00	1.7333E+00	8.0000E-01	9.9900E-01	6.2223E-03
2.7000E+01	8.4859E+00	1.8000E+00	8.0000E-01	9.9890E-01	6.4018E-03
2.8000E+01	8.6376E+00	1.8667E+00	8.0000E-01	9.9882E-01	6.5301E-03
2.9000E+01	8.7529E+00	1.9333E+00	8.0000E-01	9.9874E-01	6.6071E-03
3.0000E+01	8.8358E+00	2.0000E+00	8.0000E-01	9.9869E-01	6.6327E-03

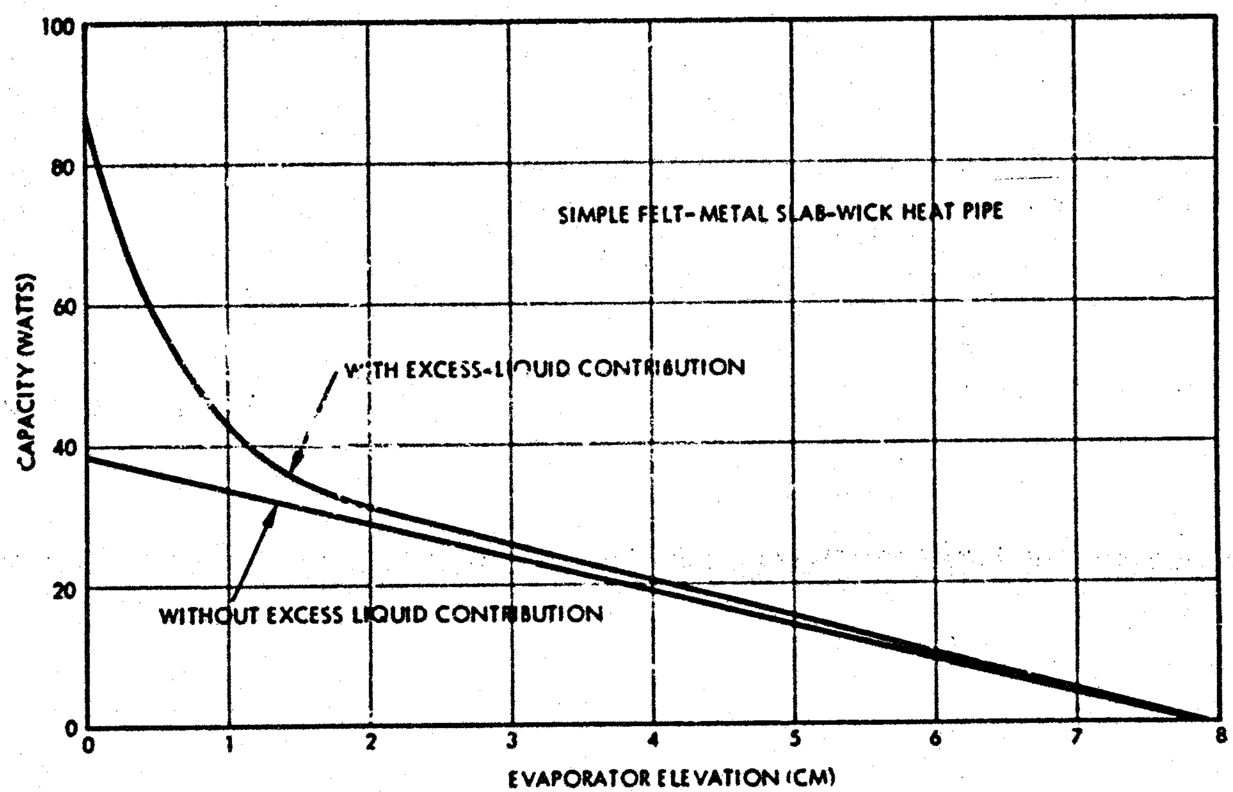

Figure 5. Capacity Vs. Elevation for Metal-Felt Slab-Wick Heat Pipe

HW - The wick height is the height in the heat-pipe cross section to the top of the wick from the lowest point in the vapor spaces.

DIAVS - The vapor-space diameter is the hydraulic diameter, four times the area divided by the wetted perimeter.

HVS - The height to the top of the lowest vapor space from the lowest point in the vapor spaces.

PERIM - Active perimeter of vapor space is the perimeter over which evaporation or condensation occurs.

TH1, TH2 - Angular groove feed locations measured positively counter-clockwise from the top of the heat pipe [see Reference (2)].

FQGRV - Radial input fraction is the fraction of heat input to a single vapor space.

Under the heading "FINAL SOLUTION," the pertinent data on the heat pipe at its maximum capacity are printed. In this case, the maximum capacity is 31 watts, the fluid charge is 5.7 grams, the vapor Reynolds number based on the average vapor velocity $\overline{u}$ in the adiabatic section and the hydraulic diameter of the vapor space is 260, and the vapor velocity head $1/2\ \rho_v\overline{u}^2$ is 4.8×10^{-4} cm of liquid. The radial Reynolds numbers, which are based on the normal velocity of the vapor, negative when towards the condensing surface and positive when away from the evaporating surface, is -2.22 in the condenser and +2.22 for the evaporator. Next the distribution of stress, static head, porosity, saturation fraction and static pressure of the vapor are listed. The static head is the contribution to stress from the gravitational acceleration.

The results of several runs for the capacity of this heat pipe as a function of elevation are shown in Figure 5. Two curves both with (IFLTS = 1) and without (IFLTS = 0) the effect of excess liquid are shown. The wick in this heat pipe was intentionally selected to have a low permeability in order to show the marked effect excess liquid can have on a heat pipe.

5.2 EXAMPLE OF GRADED-POROSITY-WICK DESIGN

In the second sample problem, we focus on the design of a graded-porosity wick. The input is given in Table VI and the output is given

in Table VII. The heat pipe has an inside diameter of 1.1 cm (HPID = 1.1), a wick thickness of 0.51 cm (WKTH = 0.51) with a fiber diameter of 0.0127 cm (DIAF = .0127). In this case the wick is horizontal (IGEOM = 0). The condenser, adiabatic and evaporator lengths are, respectively, 50, 60 and 30 cm (XQ = 50., 60., 30.).

The wick is being designed for maximum capacity when the evaporator end is elevated 2 cm (ELEV = 0., 2.). By setting IPRIMED = 0, we are requiring the wick to self-prime at the operating tilt. Because fibrous wicks exhibit capillary hysteresis, a wick with a higher capacity could be designed if the user accepts the operating constraint of first leveling the heat pipe with no load to prime the wick before elevating the evaporator end. If this option is elected, IPRIMED is set to 1.

The TRW version of GRADE II has the provision to automatically plot the wick volume density profile (the volume density is one minus the porosity). This plotting capability, which is activated by setting IPLOT = 1, utilizes plotting routines outside of standard FORTRAN, and thus it is not included in the user's manual. The plot of the volume-density distribution is shown in Figure 6. The wick begins with a porosity of .873 at the condenser end and ends with a porosity of .631 which is above the set minimum of .60 (EPSMIN = .60). The output of Table VII shows that the maximum heat-transfer rate is 85 watts, and the fluid charge is 31.1 grams of ammonia.

TABLE VI - GRADE II INPUT

GRADED-POROSITY-WICK DESIGN

```
$GRDATA
HD1=60H EXAMPLE OF GRADED-POROSITY-WICK DESIGN
HD2=60H FILE NAME  HITILT    9/20/76
LIQ=2
TKELVN=300.
HPID=1.1
WKTH=.51
IGEOM=0
NQ=3
XQ=50.,60.,30.
FQ=-1.,0.,1.
QDOT=100.
NELEV=2
XELEV=0.,140.
ELEV=0.,2.
GEE=1.
GRVS=40.
W=.018
DEPTH=.020
PHI=20.
ANGWET=0.
DIAF=.0127
S=.9
EPSMIN=.6
DX=5.
IPRIMED=0
ROUGH=.02
IPLOT=1
$END
```


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EXAMPLE OF GRADED-POROSITY-WICK DESIGN
FILE NAME HITILT 4/29/76

TABLE VII - GRADE II OUTPUT

INPUT VARIABLES AND FLUID PROPERTIES:

LIQUID NUMBER..................	LIQ =	2	
TEMPERATURE....................	TKELVN =	3.00000E+02	DEGREES KELVIN
LIQUID DENSITY.................	RHOL =	[illegible]E+02	KG/CU. M
VAPOR DENSITY..................	RHOV =	9.26424E+00	KG/CU. M
SURFACE TENSION................	ST =	1.95290E-02	NEWTONS/M
LIQUID VISCOSITY...............	VISL =	1.30130E-04	NEWTON-SEC/SQ. M
VAPOR VISCOSITY................	VISV =	[illegible]E-06	NEWTON-SEC/SQ. M
LATENT HEAT....................	HFG =	[illegible]E+06	JOULES/KG
VAPOR PRESSURE.................	PV =	[illegible]E+06	N/SQ. M
THERMAL CONDUCTIVITY OF LIQ....	RKL =	5.09320E-01	WATTS/M K
SPECIFIC HEAT RATIO............	SHRV =	1.31000E+00	
MOLECULAR WEIGHT...............	RMW =	1.70320E+01	
FREEZING TEMPERATURE...........	TF =	[illegible]E+02	DEGREES KELVIN
GRAVITATIONAL ACCELERATION.....	GEE =	1.00000E+00	STANDARD GRAVITIES
HEAT-PIPE GEOMETRY.............	IGEOM =	0	
(0=HORIZ. SLAB, 1=VERT. SLAB, 2=GENERAL)			
HEAT-PIPE INSIDE DIAMETER......	HPID =	1.10000E+00	CM
WICK THICKNESS.................	WKTH =	5.10000E-01	CM
WICK AREA......................	AW =	5.40190E-01	SQ. CM
WICK HEIGHT....................	HW =	[illegible]E-01	CM
WICK FIBER DIAMETER............	DIAF =	1.27000E-02	CM
SPECIFIED SATURATION FRACTION..	S =	9.00000E-01	
MINIMUM ALLOWABLE POROSITY.....	EPSMIN =	[illegible]E-01	
NO. SPECIFIED-POROSITY PTS.....	NEPS =	0	
NO. OF EQUAL VAPOR SPACES......	NVS =	2	
AREA OF EACH VAPOR SPACE.......	AVS =	[illegible]E-01	SQ. CM
VAPOR-SPACE DIAMETER...........	DIAVS =	[illegible]E-01	CM
HEIGHT TO TOP OF LOWEST V.S. ..	HVS =	[illegible]E-01	CM
TOTAL ACTIVE PERIMETER OF V.S. .	PERIM =	[illegible]E+00	CM

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```
GROOVE OPENING....................        W = 1.[illegible]E-02  CM
GROOVE DEPTH......................    DEPTH = 2.[illegible]E-02  CM
GROOVE HALF-ANGLE.................      PHI = 2.[illegible]E+01  DEGREES
WETTING ANGLE.....................   ANGLE1 = 0.                 DEGREES
FIRST GROOVE FEED LOCATION........      TH1 = -6.237800E+01  DEGREES FROM TOP
SECOND GROOVE FEED LOCATION.......      TH2 = 6.237800E+01   DEGREES FROM TOP
RADIAL INPUT FRACTION.............    FRADV = 5.000000E-01
WICK HEIGHT REL. TO TUBE AXIS.....    HWICK = 2.[illegible]E-01  CM
NO. GROOVES PER CM................     GRVS = 4.000000E+01   /CM

NOMINAL HEAT-TRANSFER RATE........     QDOT = 1.000000E+02   WATTS
NO. HEAT-INPUT SECTIONS...........       NQ = 3
SECTION NUMBER   1
     SECTION LENGTH...............       AQ = 5.000000E+01   CM
     HEAT-INPUT FRACTION..........       FQ = -1.000000E+00
SECTION NUMBER   2
     SECTION LENGTH...............       AQ = 6.000000E+01   CM
     HEAT-INPUT FRACTION..........       FQ = 0.
SECTION NUMBER   3
     SECTION LENGTH...............       AQ = 3.000000E+01   CM
     HEAT-INPUT FRACTION..........       FQ = 1.000000E+00

NO. ELEVATION POINTS..............    NELEV = 2
ELEVATION POINT NO.   1
     DISTANCE TO POINT............    XELEV = 0.             CM
     ELEVATION OF POINT...........     ELEV = 0.             CM
ELEVATION POINT NO.   2
     DISTANCE TO POINT............    XELEV = 1.400000E+02   CM
     ELEVATION OF POINT...........     ELEV = 2.000000E+00   CM

INTEGRATION STEP SIZE.............       DX = 5.[illegible]  CM

WICK PRIMED LEVEL ([illegible])...... [illegible] = [illegible]

LIQUID FILLETS ALONG WICK.........    IFLTS = 0

ANOTHER CASE ([illegible])........    [illegible] = [illegible]
USE LAST POROSITY DIST............  [illegible] = [illegible]
ONLY ONE INTEGRATION PASS.........    IPASS = [illegible]
PLOT POROSITY.....................    IPLOT = 1
EXTRA WICK AT BEGINNING...........      XAD = 0.             CM
```


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EXTRA WICK ON END...............	[illegible] =	[illegible]	[illegible]
HIGH TOLERANCE ON VOL. DENSITY	HIGH =	[illegible]	PERCENT
LOW TOLERANCE ON VOL. DENSITY.	LOW =	[illegible]	PERCENT
VAPOR SPACE SURFACE ROUGHNESS.	ROUGH =	[illegible]	[illegible]

FINAL SOLUTION

THE MAXIMUM HEAT-TRANSFER RATE IS........ [illegible] WATTS
THE TOTAL LIQUID IN WICK IS.............. [illegible] GRAMS
THE VAPOR REYNOLDS NUMBER IS............. [illegible]
THE MAX. VAPOR VELOCITY HEAD IS.......... [illegible] CM LIQ.
THE RADIAL REYNOLDS NUMBERS ARE:
FOR SECTION NO. [illegible]................ [illegible]
FOR SECTION NO. 2................ 0.
FOR SECTION NO. 3................ [illegible]

DISTANCE (CM)	STRESS (CM LIQ.)	STATIC HEAD (CM LIQ.)	POROSITY	SATURATION	VAPOR PRESSURE (CM LIQ.)
0.	1.01[illegible]E+00	0.	[illegible]	0.	0.
5.0000E+00	[illegible]	[illegible]	[illegible]	[illegible]	1.7318E-04
1.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.0000E+01	1.3471E+00	[illegible]	[illegible]	[illegible]	2.7739E-03
2.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	1.7315E-02
5.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9.0000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9.5000E+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.0000E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.0500E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.1000E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.1500E+02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1.2000E+02	[illegible]	1.7[illegible]E+00	6.733[illegible]E-01	4.0000E-01	7.7526E-02
1.2500E+02	[illegible]	[illegible]	[illegible]	4.0000E-01	[illegible]
1.3000E+02	6.71[illegible]E+00	1.[illegible]71[illegible]E+00	[illegible]	4.0000E-01	[illegible]
1.3500E+02	[illegible]	[illegible]	[illegible]	4.0000E-01	[illegible]772E-02
1.4000E+02	7.1[illegible]E+00	2.0000E+00	6.3117E-01	4.0000E-01	[illegible].759[illegible]E-02

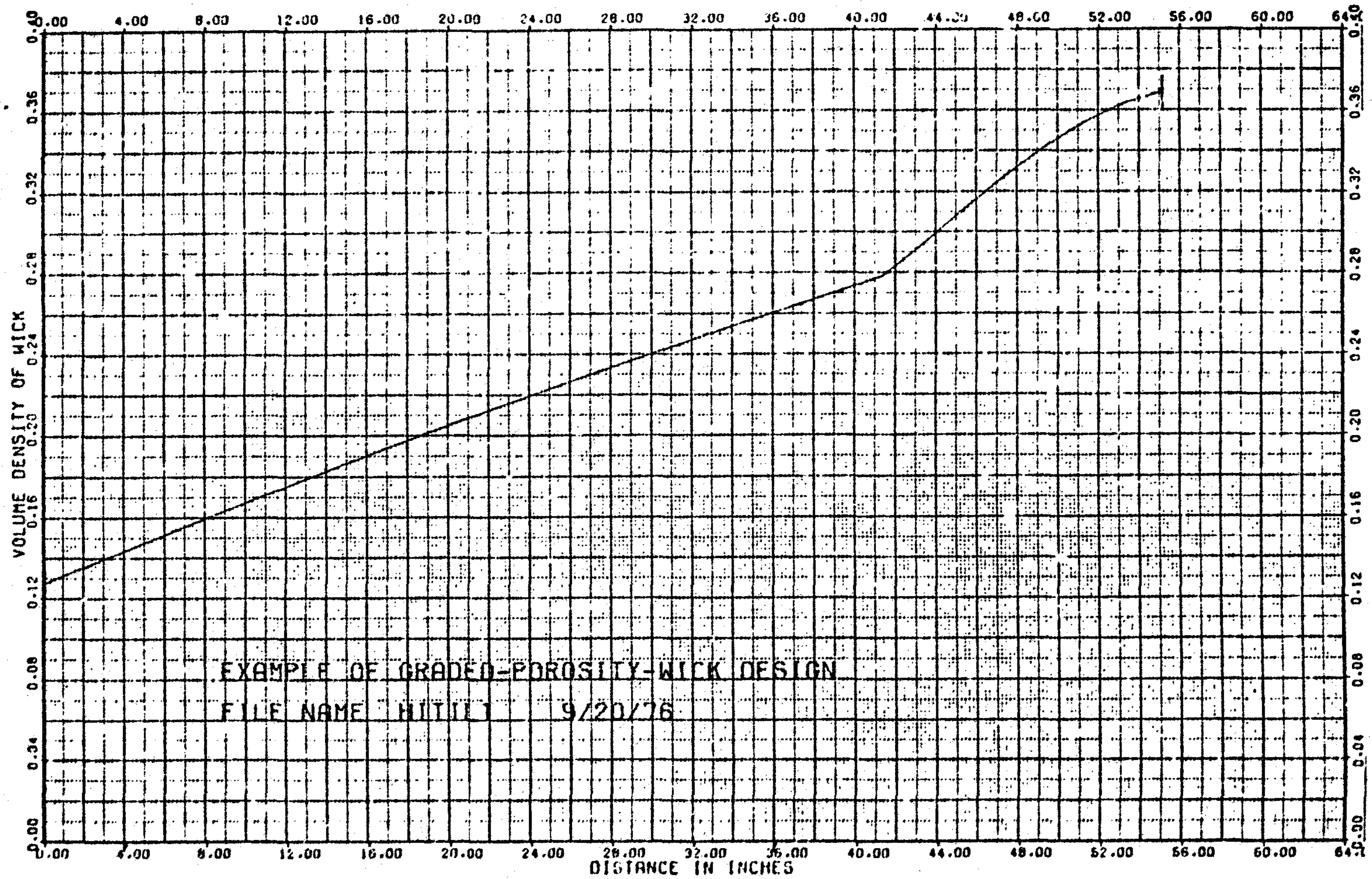

Figure 6. Example of Graded-Porosity-Wick Design, File Name Hitilt 9/20/76

6.0 REFERENCES

1. Eninger, J. E., "Computer Program GRADE for Design and Analysis of Graded-Porosity Heat-Pipe Wicks," NASA CR137618, 1974.

2. Eninger, J. E., Edwards, D. K., and Luedke, E. E., "Flight Data Analysis and Further Developments of Variable-Conductance Heat Pipes, Research Report No. 2," NASA CR137953, 1976.

3. Eninger, J. E., "Capillary Flow Through Heat-Pipe Wicks," American Institute of Aeronautics and Astronautics Paper 75-661, May 1975, Denver, Colo. To be published in the 1975 Thermophysics Volume of the AIAA Progress in Aeronautics and Astronautics series.

4. Eninger, J. E., Luedke, E. E. and Wanous, D. J., "Flight Data Analysis and Further Developments of Variable-Conductance Heat Pipes, Research Report No. 1," NASA CR137782, 1976.

APPENDIX

DESCRIPTION AND LISTING OF

GRADE II

AND

FILLET

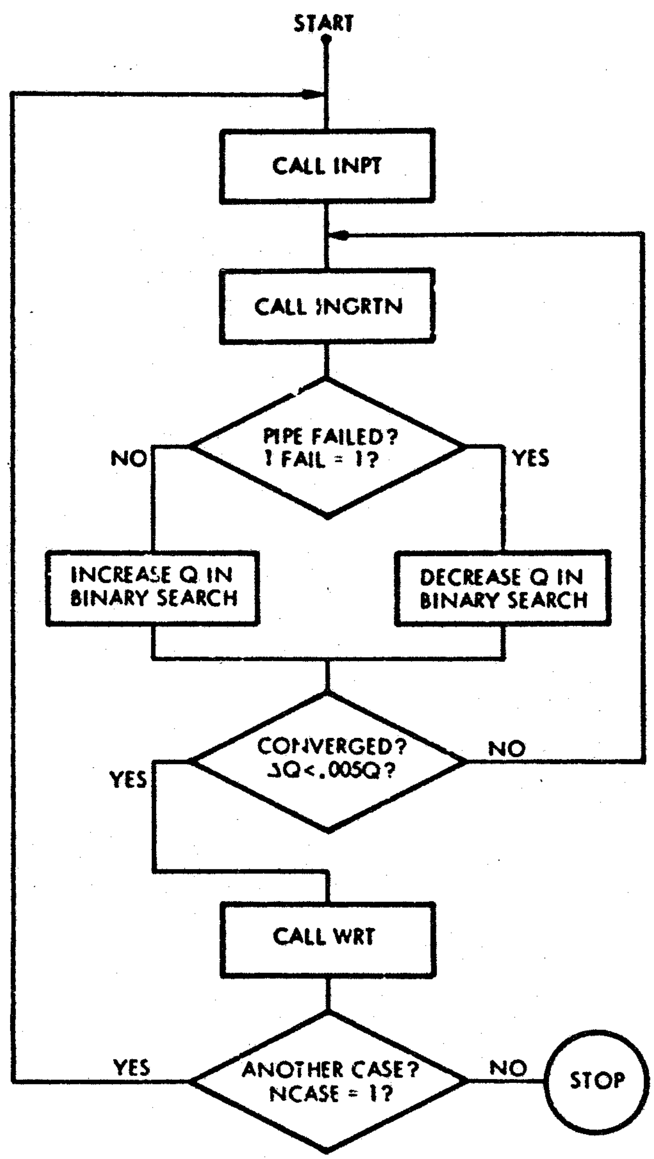

Figure 7. Flow Diagram for the Main Program, Which Searches for the Maximum Q

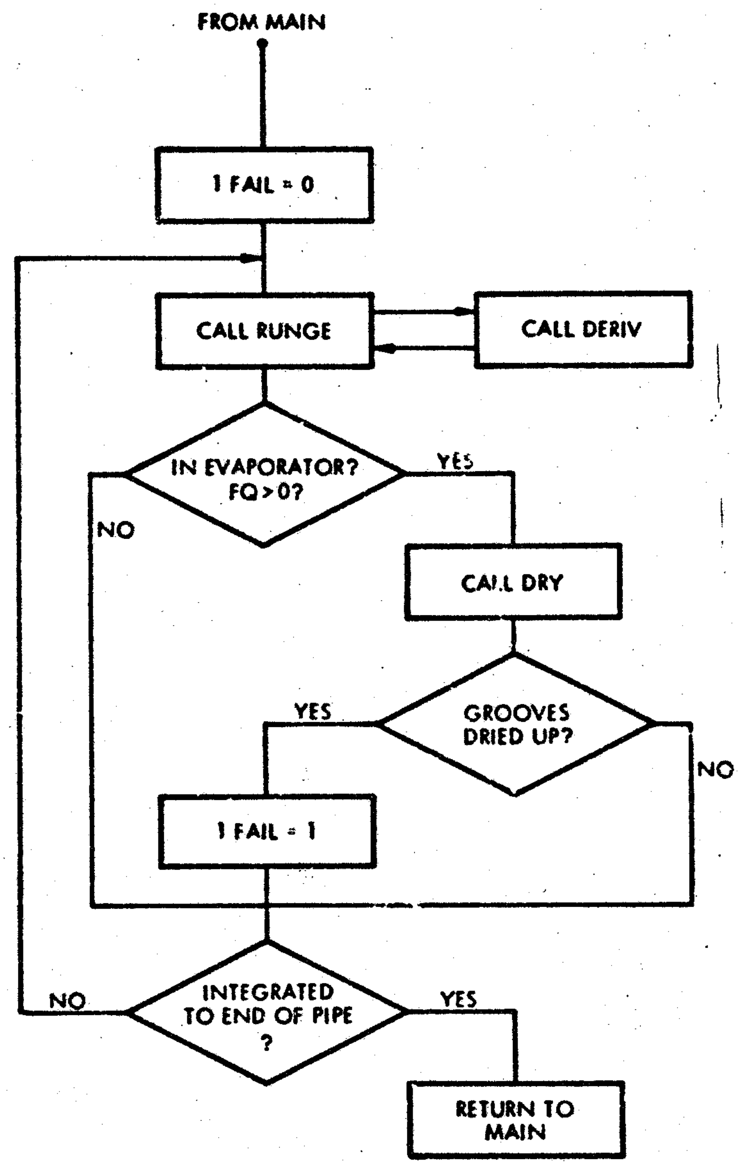

Figure 8. Flow Diagram for Subroutine INGRTN, Which Integrates Along the Pipe and Reports Whether There is a Failure

A.1 DESCRIPTION OF GRADE II

The structure of GRADE II is given in Figure 7 where the flow chart for the main program is displayed. The main program begins witn a call to INPT , which reads the data, computes parameters and calls PROPS, which calculates the fluid properties. INPT then writes all of this information. The main program next calls INGRTN, which integrates the differential equations from the condenser to the evaporator end with an assumed value Q for the heat-transport rate. If the grooves are found to dry up, INGRTN reports this by setting IFAIL = 1. Q is increased if the heat pipe has failed or decreased if it has not, in a binary search for the maximum rate. When the change in Q is less than 1/2%, the program is assumed to have converged. A call to WRT writes the final solution.

The structure of subroutine INGRTN is displayed in Figure 8. IFAIL is initialized to zero and then RUNGE, which makes a single integration step DX along the pipe, is called repeatedly. RUNGE relies on subroutine DERIV to supply values of the derivatives of the key variables. When the integration is in a region of evaporation, a call to DRY is made to check whether the grooves dry up. If they have, IFAIL is set to unity. INGRTN returns control to the main program when the evaporator end is reached.

A brief description of each subroutine is included in the listing, where the subroutines appear alphabetically.

```
              PROGRAM MAIN(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7,TAPE50)
        C
        C     MAIN  DESIGNS GRADED-POROSITY WICKS AND PREDICTS THE
        C     CAPACITY OF WICKS WITH A SPECIFIED POROSITY VARIATION
        C
000004        COMMON /PARAM/ EPS,EPSO,PHO,GEE,G,NI,NIP1,HW,ICECM,WKTH,FFIL,
000004       1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000004       2               ELEVB(10),H,FNUB,AW,AB,XTOT,DX,DZ,QDTB,QDCT,PB,
000004       3               DIAF,A(8,500),XQ(10),ZQ(10),PdS,CRVS,HREF,FCGRV,
000004       4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMX,MM,EPSS,
000004       5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000004       6               NEFS,XEFS(20),EFSX(20),NOB,SS,HVS,AAA(40),DDH(40),
000004       7               VELHD,ZCH(10),XHOP(10),XDB(10),IFLTS,STRS(40),
000004       8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFP1,
000004       9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000004        COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
        C
000004        DO 500 K=1,10
        C
000006        CALL INPT
        C     INPUT READS IN THE DATA, MAKES PRELIMINARY CALCULATIONS,
        C     AND PRINTS THE DATA
        C
        C     COMMENCE BINARY SEARCH FOR MAXIMUM  G
        C     II = 1  IF MAX G HAS NOT BEEN BRACKETED
        C     II = 2  IF MAX G HAS BEEN BRACKETED
        C
000007        II=1
000010        QDTB=1.
000012        DQDTB=.5
        C
000014        CALL INGRIN
        C     INGRIN  INTEGRATES THE DIFFERENTIAL EQUATIONS FROM THE CONDENSER
        C     TO THE EVAPORATOR FOR A SPECIFIED Q AND REPORTS WHETHER CREEVE
        C     DRY-UP HAS OCCURRED (IFAIL=0 FOR NO DRY-UP, IFAIL=1 FOR DRY-UP)
        C
000015        IF(IPASS.EQ.1) GO TO 202
```

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```
000017          DO 404 I=1,40
000021          IF(IFAIL .EQ. 1) GO TO 303
          C
000023          IF(II.EQ.1) DODTB=2.*DODTB
000027          IF(II.EQ.2) DODTB=.5*DODTB
000033          ODTB=ODTB+DODTB
000035          CALL INCRIN
000036          IF(IFAIL.EQ.1) II=2
000041          GO TO 305
          C
000042      303 IF(II.EQ.2) DODTB=.5*DODTB
000046          ODTB=ODTB-DODTB
000050          CALL INCRIN
000051          IF(IFAIL.EQ.0) II=2
          C
000053      305 IF(DODTB .LT. .005*ODTB) GO TO 202
000057      404 CONTINUE
000061      202 CONTINUE
          C
000061          CALL WRT
          C     WRT PRINTS THE FINAL SOLUTION
          C
000062          IF(IPLOT.EQ.1) CALL PLOTEM
          C     PLOTEM  PLOTS THE POROSITY VARIATION
          C
000065          IF(NCASE.EQ.0) GO TO 501
          C
000066      500 CONTINUE
000070      501 CONTINUE
000070          STOP
000072          END
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.

                    SUBROUTINE ALFA(ACON)
            C
            C       ALFA COMPUTES FRICTION FACTOR  FRF  GIVEN CONTACT ANGLE
            C       ACON  IN DEGREES
            C
000003              COMMON /AALFA/ AFIT,BFIT,CFIT,FRF
            C
000003              FRF=AFIT+BFIT*ACON+CFIT*ACON**2
000011              RETURN
000012              END
```

```
                  SUBROUTINE DCALCS
            C
            C     DCALCS  MAKES PRELIMINARY CALCULATIONS FOR GROOVE DRY-UP
            C
000002            COMMON /PARAM/ EPS,EPSO,PND,GEE,C,NI,NIP1,HM,ICHCM,WKTH,HFID,
000002           1               NG,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002           2               ELEVB(10),H,FNUF,AW,AE,XTCT,DA,DZ,DDTO,DDCT,PB,
000002           3               DIAF,A(2,500),XC(10),ZO(10),PBS,GRVS,HREF,FCGPV,
000002           4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBC,IMK,HM,EPSS,
000002           5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPPIPED,
000002           6               NEPS,XEPS(20),EFSX(20),NOB,SS,HVS,AAA(40),CCH(40),
000002           7               VELHD,ZCP(10),XPOB(10),XOB(10),IFLTS,STKS(40),
000002           8               IPASS,FFRIM,RCLCH,TH1,TH2,IEN(10),NEN,FI,FFP1,
000002           9               IPLOT,XXO,XX1,EPSMIN,HIGH,LCW,HD1(6),HD2(6)
000002            COMMON /CPROPS/ XMW,SHRV,HFG,FV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002            COMMON /GRVDTA/ ACR,PHIR,SP,CP,TP,SMAX,CMAX,PSIMR,HG,ATRI,PERIF,
000002           1                RMIN,CLAV,BCT,FLC,GFAC,VFAC,RWPK,RPD
            C
000002            PI=3.141592654
000004            RPD=PI/180.
            C
            C     GROOVE DATA
            C
000006            VISLK=VISL/RHOL
000010            ACR=ANGWET*RPD
000012            PHIR=PHI*RPD
000014            SP=SIN(PHIR)
000017            CP=COS(PHIR)
000022            TP=SP/CP
000024            PSIMAX=90.-PHI-ANGWET
000027            PSIMR=PSIMAX*RPD
000031            SMAX=SIN(PSIMR)
000034            CMAX=COS(PSIMR)
000037            HG=(W/100.)/(2.*TP)-(DEPTH/100.)
000046            BCT=2.*HG*(1.-SP)/CP
000053            ATRI=HG*HG*TP
000055            PERIF=(W/100.)/SP-BCT
```

```
RUNX COMPILER (VER.2.3M)                 04/28/76. 13.24.02.          DCALCS

000061          PMIN=(V/?00.)/(2.*SMAX)
000065          OWMX=1./(200./DEPTH+200./W)
000071          CHPV=CFF*G*(RHOL-RHOV)/ST
000076          CFAC=(RHOL-RHOV)*9.805*CEE*(HPID/100.)/(2.*ST)
000110          VFAC=((HPID/100.)/4.)*VISLK/ST
000114          RETURN
000115          END
```

```
                 SUBROUTINE DERIV(YP,Y)
          C
          C      DERIV  CALCULATES THE DERIVATIVES OF THE STRESS, HEAT INPUT,
          C      WICK LIQUID, AND PRESSURE OF THE VAPOR
          C
000005           COMMON /PARAM/ EPS,EPSO,PRO,CEE,C,XI,NIPI,HW,ICLUM,WKTH,HPIL,
000005          1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000005          2               ELEVB(10),H,FALB,AW,AB,XTOT,DX,DZ,DOTB,DOCT,FB,
000005          3               DIAF,A(F,500),XC(10),ZO(10),PBS,GPVS,HPEF,FCGRV,
000005          4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EFSS,
000005          5               NVS,AVT,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPFD,
000005          6               NEPS,NEPS(20),EPSX(20),NUR,SS,HVS,AAA(40),CDH(40),
000005          7               VELHD,ZOP(10),XKOB(10),XJP(10),IFLTS,STRS(40),
000005          8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFPI,
000005          9               IPLCT,AXU,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000005           COMMON /PROPS/ XMW,SHAV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
          C
000005           DATA R1/.3243P153/,R2/-.3.6563792/,R3/1.78147737/,
000005          1     R4/-1.R21255978/,R5/1.33C274429/,R/.2316519/,D/1.66/
          C
000005           DIMENSION YP(5),Y(5),X(11),WW(11),WP(11)
          C
000005           YP(1)=1.
000007           PR=Y(2)
          C
          C      CALCULATION OF THE ELEVATION  HB  AT LOCATION  Z
          C
000011           N=NELEV-1
000013           DO 101 I=1,N
000015           Z=Y(1)
000016           IF(Z.GE.ZELEV(I) .AND. Z.LE.ZELEV(I+1)) IMK=I
000031       101 CONTINUE
000034           DELEV=(ELEVB(IMK+1)-ELEVB(IMK))/(ZELEV(IMK+1)-ZELEV(IMK))
000041           HB=ELEVB(IMK)+(ELEVB(IMK+1)-ELEVB(IMK))*(Z-ZELEV(IMK))/
000041          1                (ZELEV(IMK+1)-ZELEV(IMK))
          C
000053           PRESS=1./(1.+PH/PBS)
```


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```
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000057          EPSS1=1./(1.+R*(RHO+(1-IPRIME)*(GE*HB)/P3S))
000072          IF(EPSS.GT.EPSS1) EPSS=EPSS1
000075          IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 103
          C
          C     CALCULATION OF THE POROSITY FOR A SPECIFIED SATURATION FRACTION
          C
000103          EPS=(EPSS-EPS1/4.5)/(1.-EPS1/4.5)
000112          SS=S
000114          GO TO 106
          C
          C     CALCULATION OF THE SATURATION FRACTION FOR A SPECIFIED POROSITY
          C
000115      103 IZ=INT((Z+1.0E-12)/DZ)
000121          EPS=SAVEPS(NI+1)
000123          IF(IZ .EQ. NI+1) GO TO 105
000125          EPS=SAVEPS(IZ)+(SAVEPS(IZ+1)-SAVEPS(IZ))*(Z-(IZ-1)*DZ)/DZ
000137      105 CONTINUE
000137          ZZ=4.55*(EPSS-EPS)/(1.-EPS)
000145          IF(ZZ .LT. 0.) ZZ=-ZZ
000147          F=(1./SQRT(2.*PI))*EXP(-ZZ*ZZ/2.)
000163          T=1./(1.+R*ZZ)
000167          T2=T*T
000171          T3=T2*T
000173          T4=T3*T
000175          T5=T4*T
000177          FF=1.-F*(B1*T+B2*T2+B3*T3+B4*T4+B5*T5)
000213          IF(EPSS.LT.EPS) FF=1.-FF
000220          SS=FF-(.22*(1.-EPS)/EPS)*F
          C
          C     CALCULATION OF THE HEAT-INPUT REGION IN WHICH  Z  FALLS
          C
000226      106 DIST=0.
000227          DO 112 I=1,NG
000231          DIST=DIST+ZG(I)
000234          IHK=I
000236          IF(Z.LT.DIST) GO TO 113
000241      112 CONTINUE
000244      113 YP(3)=-QDIN*FL(IHK)/ZG(IHK)
```

```
       C
       C      BEGIN THE CALCULATION OF VAPOR FLOW
       C
000250        RCRIT=2300.
000252        VW=ABS(FQ(IMK)*QDT*QDOT/HFG)/(RHOV*(XG(IMK)/100.)*
000252       1   FLOAT(NVS)*F(RIM/100.)
000270        REVO=(DIAVS/100.)*VW/(VISV/RHOV)
000275        WMDOT=Y(3)*(QDOT/HFG)
000300        VVAP=WMDOT/(FLOAT(NVS)*(AVS*1.0E-4)*RHOV)
000305        REV=VVAP*(DIAVS/100.)/(VISV/RHOV)
000312        VELHD=.5*RHOV*VVAP**2
000315        IF(REV.LT.RCRIT) GO TO 11
       C
       C      TURBULENT VAPOR FLOW
       C
       C      NEWTON ITERATION OF THE COLEBROOK EQ. FOR THE TURBULENT
       C      FRICTION FACTOR
       C
000320        X(1)=4.
000322        DO 50 I=1,10
000324        P1=X(I)
000326        P2=2.*ALOG10(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000342        TEST=-P1/P2
000344        IF(ABS(TEST-1.) .LT. .001) GO TO 60
000351        WW(I)=P1+P2
000354        WP(I)=1.+(5.02/REV)/(2.51*X(I)/REV+ROUGH/(3.7*DIAVS))
000370        X(I+1)=X(I)-WW(I)/WP(I)
000374     50 CONTINUE
000376     60 FFAC=1./X(I)**2
       C
000401        GO TO 12
000402     11 CONTINUE
       C
       C      LAMINAR-VAPOR-FLOW FRICTION FACTOR
       C
000402        FFAC=0.
000403        IF(REV.GT.0.) FFAC=64./REV
000406     12 CONTINUE
```

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```
        C
000406        FFAVE=FFAC
000410        IF(FO(IMK).EQ.0) GO TO 22
        C
000412        AO=.6
000414        AA=.13
000416        BB=.008
000420        FS=6./5.
000422        IF(FO(IMK) .LT. 0.) GO TO 18
        C
000424        AO=3.3
000426        AA=0.10
000430        BB=0.
000431        FS=1.65
        C
000433     18 IF(REV.GT.RCRIT) FS=1.
000437        BO=REV*FFAC/8.
000442        IF(FO(IMK).GT.0) BO=-BO
000445        IF(REVR.GT.0.) RCF=AO-(BO/REVR)*EXP(-AA*REVR-BB*REVR*REVR)
000461        FFAVE=0.
000462        IF(REV.GT.0) FFAVE=8.*REVR*(2.*FS-RCF)/REV
000471        IF(FO(IMK).GT.0) FFAVE=-FFAVE
        C
000474     22 DPVDX=(FFAVE/(DIAVS/100.))*VELHD
000500        DPVDX=DPVDX-2.*FS*VVAP*YP(3)*((QDOT/HFG)/(XTOT/100.))/
000500      1     (FLOAT(NVS)*(AVS*1.0E-4))
        C
        C     CALCULATION OF FILLET CONTRIBUTION TO FLOW
        C
000516        AAAA=0.
000517        FKA=0.
000520        IF(IFLTS.EQ.0) GO TO 61
000521        HWC=WKTH/200.
000523        IF(IGEOM.EQ.0) GO TO 40
000524        HWC=HPID/200.
000526        IF(IGEOM.EQ.1) GO TO 40
000530        HWC=(HW-HPID/2.)/100.
        C
```


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```
             C      HWC  IS THE WICK HEIGHT RELATIVE TO THE TUBE CENTER
             C
000534    40 SSTRS=PR*HW/100.-HWC
000540       DDDH=DDH(1)
000542       AAAA=AAA(1)
000544       IF(SSTRS.LT.STRS(1)) GC TO 80
000547       DO 61 I=1,NH
000551       IF(STRS(I).GE.SSTRS) GC TC 70
000554    61 CONTINUE
000557       FKA=0.
000560       AAAA=0.
000561       GO TO 81
000562    70 AAAA=AAA(I-1)+(AAA(I)-AAA(I-1))*(SSTRS-STRS(I-1))/
000562     1      (STRS(I)-STRS(I-1))
000574       DDDH=DDH(I-1)+(DDH(I)-DDH(I-1))*(SSTRS-STRS(I-1))/
000574     1      (STRS(I)-STRS(I-1))
000606    80 FKA=(AAAA/(HW/100.)**2)*(DDDH**2/(DIAF/100.)**2)/32.
000616    81 CONTINUE
          C
000616       YP(2)=FNUB*Y(3)/(D*FERM(EFS,EPSS)*AB+FKA)+DELEV*GEE
000616     1      +((XTOT/100.)/PND)*DPVDX
000636       YP(5)=((XTOT/100.)/PND)*DPVDX
000642       YP(4)=EPS*SS+AAAA/(AW/10000.)
000647       RETURN
000650       END
```


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RUNX COMPILER (VER.2.3M)   09/28/76. 13.24.02.

```
                 SUBROUTINE DRY
          C
          C      DRY, GIVEN AN EVAPORATOR HEAT LOAD, GROOVE SHAPE, A BACK STRESS
          C      AT SOME REFERENCE HEIGHT, AND A PAIR OF FEED ANGLES, DETERMINES
          C      WHETHER DRY UP, DEFINED AS MENISCUS CONTACT ON THE TRAPEZOIDAL
          C      GROOVE BOTTOM, OCCURS BETWEEN THE ANGLES.
          C
000002           COMMON /PARAM/ EPS,EPSO,PND,GEE,G,NI,NIP1,HW,IGEOM,WKTH,HPID,
000002          1               NQ,FQ(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002          2               ELEVB(10),H,FNUB,AW,AB,XTGT,DX,DZ,QDTB,QDOT,PB,
000002          3               DIAF,A(6,500),XQ(10),ZQ(10),PBS,GRVS,HREF,FCGRV,
000002          4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EPSS,
000002          5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002          6               NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),CDH(40),
000002          7               VELHD,ZCP(10),XKOB(10),XOP(10),IFLTS,STRS(40),
000002          8               IPASS,PEPIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000002          9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002           COMMON /CPROPS/ XMW,SHPV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002           COMMON /GRVDTA/ ACR,PHIR,SP,CP,TP,SMAX,CMAX,PSIMR,HG,ATRI,PEPIF,
000002          1                RMIN,CURV,BCT,FLO,GFAC,VFAC,RWMN,RPD
          C
000002           DODL=QDTB*QDOT*FQ(IMK)/(XQ(IMK)/100.)
000007           FLO=(DODL/(GRVS*100.))*FCGRV/HFG
000013           RCAP=ST/(PB*PNO)
          C
          C      CONDITIONS AT ANGLE 1
          C
000016           I1=1
000017           H1=((HPID/100.)/2.)*COS(TH1*RPD)-(HREF/100.)
000033           R1=1./((1./RCAP)+(H1*CURV))
000040           IF(R1.LT.RWMN) I1=0
          C
          C      CONDITIONS AT ANGLE 2
          C
000044           I2=1
000045           H2=((HPID/100.)/2.)*COS(TH2*RPD)-(HREF/100.)
000061           R2=1./((1./RCAP)+(H2*CURV))
```


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```
000066         IF(R2.LT.RWMN) I2=0
          C
          C    START OF SEARCH FOR POSSIBLE DRY ZONE
          C
000072         IF(I1.NE.1 .AND. I2.NE.1) GO TO 998
          C    THE ENTIRE REGION IS DRY BY VIRTUE OF THE WICK-MENISCUS
          C    CONTACT POSTULATE
          C
000101         ISRCH=1
000102         DTSTGN=(TH2-TH1)/2.
000105         TSTGN=TH1
          C
000107     101 CONTINUE
000107         TSTGN=TSTGN+DTSTGN
          C
000111         CALL WET(TSTGN,R1,R2,TL1,TL2)
          C    WET MARCHES FROM  TH1  POSITIVELY TO  TSTGN  AND FROM
          C    TH2  NEGATIVELY TO  TSTGN  AND REPORTS THE ANGLE, IF ANY,
          C    AT WHICH THE GROOVES CEASE TO BE WET
          C
000115         IF(I1.EQ.0) TL1=TH1
000120         IF(I2.EQ.0) TL2=TH2
          C
000123         IF(TL1.GE.TSTGN-.001*ABS(TSTGN) .AND.
000123        1   TL2.LE.TSTGN+.001*ABS(TSTGN)) GO TO 997
          C    THE REGION IS FULLY WET IF THIS STATEMENT EXECUTES
          C
000141         IF(TL1.LT.TSTGN-.001*ABS(TSTGN) .AND.
000141        1   TL2.GT.TSTGN+.001*ABS(TSTGN))GO TO 998
          C    DRY OUT IS CERTAIN TO EXIST SOMEWHERE IN THE REGION
          C
000157         DTSTGN=ABS(DTSTGN)/2.
000162         IF(ABS(TL1-TSTGN) .GT. ABS(TL2-TSTGN)) DTSTGN=-DTSTGN
000171         ISRCH=ISRCH+1
000173         IF(ISRCH.LT.20) GO TO 101
000176         GO TO 998
          C
000177     997 CONTINUE
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.         DRY

            C      THE GROOVES ARE WET
000177             IFAIL=0
000200             GO TO 999
000201        998  CONTINUE
            C      THE GROOVES ARE DRY
000201             IFAIL=1
000202        999  CONTINUE
000202             RETURN
000203             END
```

```
000017          IF(ILOW.GT.6) ILOW=6
000023          IF(IHI.GT.6) IHI=6
000027          FAC=(PHI-10.*ILOW)/10.
000034          DO 100 I=1,3
000036      100 FR(I)=FRIC(ILOW,I)+FAC*(FRIC(IHI,I)-FRIC(ILOW,I))
          C
          C     ALLOWANCE FOR TRAPEZOIDAL SHAPE
          C
000051          AA=(W/100.)/2.
000054          BB=AA/TAN(3.1415965*PHI/180.)
000062          CC=SQRT(AA**2+BB**2)
000070          EPSLN=(BB-(DEPTH/100.))/CC
000074          IF(EPSLN.GT.0.4) GO TO 101
000100          IF(EPSLN.GT.0.2) GO TO 102
000104          DO 103 I=1,3
000106          FUDGE=1.0+FF(1,I)*(1.-((0.2-EPSLN)/0.2)**2)
000116      103 FR(I)=FR(I)*FUDGE
000122          GO TO 104
000123      102 CONTINUE
000123          DO 105 I=1,3
000125          FUDGE=1.0+FF(1,I)+(FF(2,I)-FF(1,I))*(EPSLN-0.2)/0.2
000137      105 FR(I)=FR(I)*FUDGE
000143          GO TO 104
000144      101 CONTINUE
000144          DO 106 I=1,3
000146          FF1=1.+FF(1,I)
000151          FUDGE=(96./FR(I)-FF1)*((EPSLN-0.4)/0.6)**2
000160      106 FR(I)=FR(I)*FUDGE
000164      104 CONTINUE
          C
          C     PARABOLIC FIT FOR VARIATION WITH CONTACT ANGLE
          C
000164          X1=0.0
000166          X2=15.
000170          X3=90.-PHI
000172          Y1=FR(1)
000174          Y2=FR(2)
000176          Y3=FR(3)
```

RUNX COMPILER (VER.2.3M)   09/28/76. 13.24.02.

```
                   SUBROUTINE FACTOR
          C
          C        FACTOR  CALCULATES CURVE FIT FOR THE GROOVE FRICTION FACTOR
          C
000002             COMMON /PARAM/ EPS,EPSC,PNO,GEE,C,NI,NIP1,HW,ICEOM,WAIH,HFIC,
000002        1                   NG,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002        2                   ELEVB(10),H,FNLB,AW,AB,XICT,JX,DZ,COTB,QUCT,FB,
000002        3                   DIAF,A(6,500),XG(10),ZG(10),PBS,GPVS,HREF,FCCRV,
000002        4                   NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMK,NH,EPSS,
000002        5                   NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPEC,
000002        6                   NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),DDH(40),
000002        7                   VELHG,ZOB(10),XKOB(10),XOB(10),IFLTS,STRS(40),
000002        8                   IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,FI,FIP1,
000002        9                   IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002             COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002             COMMON /CRVDTA/ ACR,PHIP,SF,CF,TP,SMAX,CMAX,PSIMR,HG,ATRI,PERIF,
000002        1                    RMIN,CURV,BCT,FLO,GFAC,VFAC,RWPN,PPO
000002             COMMON /AALFA/ AFIT,BFIT,CFIT,IRFC
          C
000002             DIMENSION FRIC(6,3),FF(2,3),FR(3),Y(3),ALPHA(10),FRF(10)
          C
          C        FRICTION-FACTOR DATA FOR TRIANGULAR SHAPE
          C
000002             DATA (FRIC(I),I=1,18) /43.78,40.59,37.80,35.22,32.80,30.45,
000002        1                          46.72,46.22,46.03,46.06,46.42,47.36,
000002        2                          49.79,52.78,55.32,56.73,56.72,55.32/
          C
          C        CORRECTION FACTOR FOR TRAPEZOIDAL SHAPE
          C
000002             DATA (FF(I),I=1,6) /0.06,0.36,0.13,0.14,0.17,0.25/
          C
          C        FRICTION FACTOR FOR TRIANGULAR SHAPE BY INTERPOLATION
          C
000002             ILOW=PHI/10.
000005             IHI=ILOW+1
000007             IF(ILOW.LT.1) ILOW=1
000013             IF(IHI.LT.1) IHI=1
```

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```
RUNX COMPILER (VER.2.3M)                09/28/76. 13.24.02.        FACTOR

000200          D1=X2*X3**2-X3*X2**2
000205          D2=X1*X3**2-X3*X1**2
000212          D3=X1*X2**2-X2*X1**2
000217          DD=D1-D2+D3
000222          XA=Y1*D1-Y2*D2+Y3*D3
000230          AFIT=XA/DD
000232          XB1=Y2*X3**2-Y3*X2**2
000237          XB2=Y1*X3**2-Y3*X1**2
000244          XB3=Y1*X2**2-Y2*X1**2
000251          XB=XB1-XB2+XB3
000254          BFIT=XB/DD
000256          XC=(X2*Y3-Y2*X3)-(X1*Y3-Y1*X3)+(X1*Y2-Y1*X2)
000271          CFIT=XC/DD
          C
000273          RETURN
000274          END
```

```
                 FUNCTION FINT(EPSO,EPS)
          C
          C      FINT  CALCULATES THE INTEGRAND FOR THE CALCULATION OF
          C      THE PERMEABILITY BY  PERM
          C
000005           OME=1.-EPS
000007           OMEO=1.-EPSO
000011           OME2=OME*OME
000013           FK=(3./8.)*(EPS/OME)/(4.*EPS/(4.*OME-OME2-2.*ALOG(OME)-3.)
000013          1   -8./(ALOG(OME)+(1.-OME2)/(1.+OME2)))
000044           F=(1.8/OMEO)*EXP(-10.3*(EPS-EPSO)*(EPS-EPSO)/(OMEO*OMEO))
000057           FINT=F*FK
000061           RETURN
000063           END
```

RUNX COMPILER (VER.2.3M)   09/26/76. 13.24.02.

```
                     SUBROUTINE INGRTN
             C
             C       INGRTN  INTEGRATES THE DIFFERENTIAL EQUATIONS THE LENGTH
             C       OF THE HEAT PIPE AND REPORTS WHETHER THE GROOVES DRY-UP
             C
000002               COMMON /PARAM/ EPS,EPSO,PNC,GFE,G,AI,NIP1,HW,IGLGM,WNTH,HRIC,
000002              1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002              2               ELEVB(10),H,FNLB,AW,AB,KTCT,DX,DZ,ODTB,UDCT,FB,
000002              3               DIAF,A(8,500),XC(10),ZO(10),PBS,GFVS,HREF,ECCRV,
000002              4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PRO,IMN,NH,EPSS,
000002              5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002              6               NEPS,XEPS(20),EPSX(20),NOR,SS,HVS,AAA(40),LDF(40),
000002              7               VELHC,ZOH(10),XROW(10),XOB(10),IFLTS,STPS(40),
000002              8               IPASS,FEPIF,POUCH,TH1,TH2,IEV(10),NEV,PI,FFP1,
000002              9               IPLOT,XXO,XA1,EPSMIN,HIGH,LOW,HC1(6),HC2(6)
000002               DIMENSION Y(5),YP(5)
000002               COMMON /PROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
             C
             C       A(1,J)  IS THE DISTANCE  (=Y(1))
             C       A(2,J)  IS THE STRESS  (=Y(2))
             C       A(3,J)  IS THE MASS-FLOW RATE  (=Y(3))
             C       A(4,J)  IS THE MASS OF LIQUID IN THE WICK  (=Y(4))
             C       A(5,J)  IS THE POROSITY  EPS
             C       A(6,J)  IS THE CONTRIBUTION TO STRESS FROM CHANGE OF ELEVATION
             C       A(7,J)  IS THE SATURATION FRACTION
             C       A(8,J)  IS THE VAPOR PRESSURE  (=Y(5))
             C
000002               A(1,1)=0.
000003               A(2,1)=PRO
000005               A(3,1)=0.
000006               A(4,1)=0.
000007               A(8,1)=0.
000010               Y(1)=A(1,1)
000012               Y(2)=A(2,1)
000014               Y(3)=A(3,1)
000016               Y(4)=A(4,1)
000020               Y(5)=A(8,1)
```

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```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.        INCRTA

000022          IFAIL=0
          C
000023          CALL DERIV(YP,Y)
          C     DERIV  CALCULATES THE DERIVATIVES OF  Y(1) THRU Y(5)
          C
000025          IOP=1
000026          ICHK=0
000027          A(6,1)=EPS
000031          DO 121 I=2,NIP1
          C
000033          CALL RUNGE(Y,YP,DZ)
          C     RUNGE  MAKES ONE INTEGRATION STEP BY THE RUNGE-KUTTA METHOD
          C
          C     IF THE STRESS IS EXCESSIVE, THE INTEGRATION IS ABORTED
          C
000036          IF(EPSS .LT. 0.2) IFAIL=1
000042          IF(EPSS .LT. 0.2) GO TO 125
          C
000045          DO 110 J=1,4
000047          A(J,I)=Y(J)
000053      110 CONTINUE
000055          A(6,I)=EPS
000060          IF(EPS.LT.EPSMIN) ICHK=1
000064          A(7,I)=SS
000067          A(8,I)=Y(5)
          C
          C     THE STRESS IS INCREASED IF THERE IS A VAPOR-SPACE OBSTRUCTION
          C
000072          IF(NOB.EQ.0)GO  TO 120
000073          IF(Y(1).LT.ZOB(ICH)) GO TO 120
000076          Y(2)=Y(2)+XKOB(ICH)*VELHD/RHO
000102          Y(5)=Y(5)+XKOB(ICH)*VELHD/RHO
000106          A(2,I)=Y(2)
000111          A(8,I)=Y(5)
000114          IOP=IOP+1
000116      120 CONTINUE
          C
          C     THE GROOVES ARE CHECKED WHERE THE STRESS IS MAXIMUM
```

```
          C      IN EACH EVAPORATOR
          C
000116           IF(FO(IMK).LE.0) GO TO 121
000120           IF(A(2,I-1).GE.A(2,I)) GO TO 33
000126           DO 40 K=1,NEV
000130           IF(I.EQ.IEV(K)) GO TO 33
000133        40 CONTINUE
000136           GO TO 121
000137        33 PB=Y(2)
          C
000141           CALL DRY
          C      DRY  DETERMINES WHETHER THE GROOVES DRY-UP (IFAIL=1 FOR DRY-UP)
          C
000142       121 CONTINUE
000145           IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 125
000153           IF(ICHK.EQ.1) IFAIL=1
000156       125 RETURN
000157           END
```

RUNX COMPILER (VER.2.3M)   09/28/76. 13.24.02.

```
                      SUBROUTINE INPT
                C
                C     INPT  READS IN THE DATA, MAKES PRELIMINARY CALCULATIONS,
                C     AND WRITES THE DATA
                C
000002                COMMON /PARAM/ EPS,EPSC,EPO,GEE,C,NI,NIP1,MW,ILECM,WWIM,HFID,
000002          1                    NO,FC(10),FLEV,XFLEV(10),ZELEV(10),ELEV(10),
000002          2                    ELEVB(10),H,FNLB,AW,AO,XICT,DX,C2,CDIA,ODCT,FO,
000002          3                    DIAF,AIH,SCO,XC(10),ZC(10),PBS,GRVS,HREF,FCCRV,
000002          4                    NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NF,EPSS,
000002          5                    NVS,AVS,VFF,DIAVS,WDEPTH,PHI,ANGWT,S,IPRIP,C,
000002          6                    NZVS,XEFS(20),EPSX(20),NOO,SS,HVS,AAA(40),DCF(40),
000002          7                    VELMC,ZCF(10),XFOP(10),ZHB(10),IFLT,,STPS(40),
000002          8                    IPASS,PERIM,ROUCH,TH1,TH2,IEV(10),NFV,PI,FFP1,
000002          9                    IPLOT,XBG,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002                COMMON /CPRCPS/ AMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002                DATA HD1/6*1H /,HD2/6*1H /
000002                DATA W/1.455/,C/3.0C/,PI/3.14159265/,E/1.16/
000002                DATA C0/2.515517/,C1/.802853/,C2/.010328/,
000002          1          D1/1.432788/,D2/.189269/,D3/.001308/
                C
000002                NAMELIST /GRDATA/ LIC,TKELVN,RHOL,,T,VISL,HFG,CEE,AW,HW,DIAF,
000002          1                         DIAVS,CDCT,FC,FC,HLEV,XELEV,ELEV,IGECM,WPIM,
000002          2                         DX,HD1,HD2,XC,NCASE,LASTEPS,HPID,W,IPRIPIC,
000002          3                         NVS,AVS,HVS,FEPS,XEPS,EPSX,DEPTH,PHI,ANGWT,
000002          4                         NCB,PHCV,ROUCH,VISV,FUCRV,IFLTS,
000002          5                         ANFAC,XNLB,XCB,IPASS,PERIM,TH1,TH2,S,HREF,
000002          6                         EPSMIN,GRVS,IPLOT,XXG,XX1,HIGH,LOW
                C
000002                READ(5,GRDATA)
000005                IF(IFLTS.EQ.0) GO TO 2
000006                REWIND 7
000010                READ(7) NN,(STPS(I),I=1,NF),(AAA(I),I=1,NN),(DCF(I),I=1,NF)
000040              2 TRANK=1.8*TKELVN
000042                CALL PROPS(LIC,TRANK)
000044                IF(ITC.EQ.0) GO TO 10
000045                ST=4.45E-3.2*1*ST
```


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```
000047          RHOL=.4536*3.281**3*RHOL
000052          RHOV=.4536*3.281**3*RHOV
000055          VISL=4.448*3.281**2*3600.*VISL
000061          VISV=4.448*3.281**2*3600.*VISV
000065          HFG=(1055.*2.205)*HFG
000070          PV=4.448*39.37**2*PV
000073          XKL=.2070*3.281*1.8*XKL
000075          TF=TF/1.8
000077       10 CONTINUE
         C
000077          CALL DCALCS
         C      DCALCS  MAKES PRELIMINARY CALCULATIONS NEEDED FOR GROOVE-
         C      DRY-OUT PREDICTIONS
         C
000100          CALL FACTOR
         C      FACTOR COMPUTES FRICTION FACTOR COEFFICIENTS
         C
000101          IF(ICFCM.EQ.2) GO TO 11
000103          ALPHA=ASIN(WKTH/HPID)
000110          AW=.5*HPID*HPID*(ALPHA+SIN(ALPHA)*COS(ALPHA))
000121          AVS=PI*HPID*HPID/8.-AW/2.
000126          PERIM=(PI/2.-ALPHA)*HPID
000132          DIAVS=4.*AVS/(PERIM+HPID*COS(ALPHA))
000141          HW=(HPID+WKTH)/2.
000144          NVS=2
000145          HVS=(HPID-WKTH)/2.
000150          TH1=-(PI/2.-ALPHA)*180./PI
000154          TH2=-TH1
000156          FCGPV=.5
000160          WEFF=WKTH/2.
000162          IF(ICFCM.EQ.0) GO TO 11
000163          HVS=HPID*COS(ALPHA)
000167          HW=.5*HPID*(1.+COS(ALPHA))
000175          TH1=-(PI-ALPHA)*180./PI
000201          TH2=-ALPHA*180./PI
000204          WEFF=HPID/2.
000206       11 CONTINUE
         C
```

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```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.          INPT
000206          WRITE(6,900) HD1,HD2
000216          WRITE(6,901)
000222          WRITE(6,902) LIQ
000230          WRITE(6,904) TKELVN
000236          WRITE(6,906) RHOL
000244          WRITE(6,907) RHOV
000252          WRITE(6,908) ST
000260          WRITE(6,910) VISL
000266          WRITE(6,911) VISV
000274          WRITE(6,912) HFG
000302          WRITE(6,986) PV
000310          WRITE(6,988) XKL
000316          WRITE(6,990) SHRV
000324          WRITE(6,992) XMW
000332          WRITE(6,994) TF
000340          WRITE(6,914) GEE
000346          WRITE(6,922) IGEOM
000354          WRITE(6,924) HPID
000362          WRITE(6,925) WKTH
000370          WRITE(6,916) AW
000376          WRITE(6,918) HW
000404          WRITE(6,920) DIAF
000412          WRITE(6,959) S
000420          WRITE(6,968) EPSMIN
000426          WRITE(6,970) NEPS
000434          IF(NEPS.EQ.0) GO TO 4
000435          DO 3 I=1,NEPS
000437          WRITE(6,972) I,XEPS(I),EPSX(I)
000451        3 CONTINUE
000454        4 WRITE(6,960) NVS
000462          WRITE(6,962) AVS
000470          WRITE(6,926) DIAVS
000476          WRITE(6,927) HVS
000504          WRITE(6,929) PERIM
000512          WRITE(6,974) W
000520          WRITE(6,978) DEPTH
000526          WRITE(6,976) PHI
000534          WRITE(6,980) ANGWET
```


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```
RUNX COMPILER (VER.2.3M)                09/28/76. 13.24.02.          INPT

000542        WRITE(6,982) TH1
000550        WRITE(6,984) TH2
000556        WRITE(6,996) FCGRV
000564        WRITE(6,998) HREF
000572        WRITE(6,999) GRVS
000600        WRITE(6,928) QDOT
000606        WRITE(6,930) NQ
000614        DO 5 I=1,NQ
000616        WRITE(6,932) I,XQ(I),FQ(I)
000630      5 CONTINUE
000633        WRITE(6,934) NELEV
000641        DO 6 I=1,NELEV
000643        WRITE(6,936) I,XELEV(I),ELEV(I)
000655      6 CONTINUE
000660        WRITE(6,938) DX
000666        WRITE(6,971) IPRIMED
000674        WRITE(6,909) IFLTS
000702        WRITE(6,940) NCASE
000710        WRITE(6,942) LASTEPS
000716        WRITE(6,945) IPASS
000724        WRITE(6,946) IPLOT
000732        IF(IPLOT.EQ.0) GO TO 7
000733        WRITE(6,947) XX0
000741        WRITE(6,948) XX1
000747        WRITE(6,950) HIGH
000755        WRITE(6,956) LOW
000763      7 CONTINUE
000763    900 FORMAT(1H1,4X,6A10,/5X,6A10)
000763    901 FORMAT(//5X,38H INPUT VARIABLES AND FLUID PROPERTIES://)
000763      1              5X,37H INPUT VARIABLES AND FLUID PROPERTIES*//)
000763    902 FORMAT( 10X,42HLIQUID NUMBER.................       LIC = ,I2)
000763    904 FORMAT( 10X,42HTEMPERATURE...................     TKELVN = ,
000763      1           F12.5,16H  DEGREES KELVIN)
000763    906 FORMAT( 10X,42HLIQUID DENSITY................       RHOL = ,
000763      1           F12.5,16H  KG/CU. M        )
000763    907 FORMAT( 10X,42HVAPOR DENSITY.................       RHOV = ,
000763      1           F12.5,16H  KG/CU. M        )
000763    908 FORMAT( 10X,42HSURFACE TENSION...............         ST = ,
```

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```
000763          1          F12.5,16H  NEWTONS/M        )
000763        910 FORMAT( 10X,42HLIQUID VISCOSITY..............      VISL = ,
000763          1          F12.5,18H  NEWTON-SEC/SQ. M)
000763        911 FORMAT( 10X,42HVAPOR VISCOSITY...............      VISV = ,
000763          1          F12.5,18H  NEWTON-SEC/SQ. M)
000763          1          F12.5)
000763        912 FORMAT( 10X,42HLATENT HEAT...................       HFG = ,
000763          1          F12.5,16H  JOULES/KG        )
000763        986 FORMAT( 10X,42HVAPOR PRESSURE................        PV = ,
000763          1          F12.5,16H  N/SQ. M          )
000763        988 FORMAT( 10X,42HTHERMAL CONDUCTIVITY OF LIQ...       XKL = ,
000763          1          F12.5,16H  WATTS/M K        )
000763        990 FORMAT( 10X,42HSPECIFIC HEAT RATIO...........      SHRV = ,
000763          1          F12.5,16H                   )
000763        992 FORMAT( 10X,42HMOLECULAR WEIGHT..............       XMW = ,
000763          1          F12.5,16H                   )
000763        994 FORMAT( 10X,42HFREEZING TEMPERATURE..........        TF = ,
000763          1          F12.5,16H  DEGREES KELVIN)
000763        914 FORMAT(/10X,42HGRAVITATIONAL ACCELERATION....       GEE = ,
000763          1          F12.5,20H  STANDARD GRAVITIES)
000763        916 FORMAT(/10X,42HWICK AREA.....................        AW = ,
000763          1          F12.5,16H  SQ. CM           )
000763        918 FORMAT( 10X,42HWICK HEIGHT...................        HW = ,
000763          1          F12.5,16H  CM               )
000763        920 FORMAT( 10X,42HWICK FIBER DIAMETER...........      DIAF = ,
000763          1          F12.5,16H  CM               )
000763        922 FORMAT(/10X,42HHEAT-PIPE GEOMETRY............     IGEOM = ,
000763          1          I2/15X,40H(0=HORIZ. SLAB, 1=VERT. SLAB, 3=GENERAL) ,/)
000763        924 FORMAT( 10X,42HHEAT-PIPE INSIDE DIAMETER.....      HPID = ,
000763          1          F12.5,16H  CM               )
000763        925 FORMAT( 10X,42HWICK THICKNESS................      WKTH = ,
000763          1          F12.5,16H  CM               )
000763        950 FORMAT( 10X,42HSPECIFIED SATURATION FRACTION.         S = ,
000763          1          F12.5)
000763        968 FORMAT( 10X,42HMINIMUM ALLOWABLE POROSITY....    EPSMIN = ,
000763          1          F12.5)
000763        970 FORMAT(/10X,42HNO. SPECIFIED-POROSITY PTS....      NEPS = ,
000763          1          I2)
```

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000763      971 FORMAT(/10X,42HWICK PRIMED LEVEL (1=YES).....  IPRIMED = ,
000763        1          I2)
000763      900 FORMAT(/10X,42HLIQUID FILLETS ALONG WICK.....    IFLTS = ,
000763        1          I2)
000763      972 FORMAT(10X,21HPOROSITY POINT NO.    ,I2/
000763        1          15X,37HDISTANCE TO POINT.........      XEPS = ,
000763        2          F12.5,10H  CM       /
000763        3          15X,37HPOROSITY AT POINT........      EPSX = ,
000763        4          F12.5)
000763      960 FORMAT(/10X,42HNO. OF EQUAL VAPOR SPACES.....        NVS = ,
000763        1          I2)
000763      962 FORMAT( 10X,42HAREA OF EACH VAPOR SPACE......        AVS = ,
000763        1          F12.5,16H  SQ. CM            )
000763      924 FORMAT( 10X,42HVAPOR-SPACE DIAMETER..........      DIAVS = ,
000763        1          F12.5,16H  CM                )
000763      927 FORMAT( 10X,42HHEIGHT TO TOP OF LOWEST V.S. .        HVS = ,
000763        1          F12.5,16H  CM                )
000763      920 FORMAT( 10X,42HTOTAL ACTIVE PERIMETER OF V.S.      PERIM = ,
000763        1          F12.5,16H  CM                )
000763      928 FORMAT(/10X,42HNOMINAL HEAT-TRANSFER RATE....       QDOT = ,
000763        1          F12.5,16H  WATTS             )
000763      930 FORMAT( 10X,42HNO. HEAT-INPUT SECTIONS.......         NC = ,
000763        1          I2)
000763      932 FORMAT( 10X,16HSECTION NUMBER  ,I2/
000763        1          15X,37HSECTION LENGTH...........        XO = ,
000763        2          F12.5,10H  CM       /
000763        3          15X,37HHEAT-INPUT FRACTION......        FO = ,
000763        4          F12.5)
000763      934 FORMAT(/10X,42HNO. ELEVATION POINTS..........      NELEV = ,
000763        1          I2)
000763      936 FORMAT(10X,21HELEVATION POINT NO.   ,I2/
000763        1          15X,37HDISTANCE TO POINT........     XELEV = ,
000763        2          F12.5,10H  CM       /
000763        3          15X,37HELEVATION OF POINT.......      ELEV = ,
000763        4          F12.5,10H  CM       )
000763      938 FORMAT(/10X,42HINTEGRATION STEP SIZE.........         DX = ,
000763        1          F12.5,16H  CM                )
000763      940 FORMAT(/10X,42HANOTHER CASE (0=NO, 1=YES)....      NCASE = ,
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```
000763        1          I2)
000763      942 FORMAT( 10X,42HUSE LAST POROSITY DISTN........  LASTEPS = ,
000763        1          I2)
000763      945 FORMAT( 10X,42HONLY ONE INTEGRATION PASS.....    IPASS = ,
000763        1          I2)
000763      974 FORMAT(/10X,42HGROOVE OPENING..................      W = ,
000763        1          F12.5,16H  CM            )
000763      978 FORMAT( 10X,42HGROOVE DEPTH.....................    DEPTH = ,
000763        1          F12.5,16H  CM            )
000763      976 FORMAT( 10X,42HGROOVE HALF-ANGLE.............       PHI = ,
000763        1          F12.5,16H  DEGREES       )
000763      980 FORMAT( 10X,42HWETTING ANGLE...................  ANGWET = ,
000763        1          F12.5,16H  DEGREES       )
000763      982 FORMAT( 10X,42HFIRST GROOVE FEED LOCATION....       TH1 = ,
000763        1          F12.5,18H  DEGREES FROM TOP)
      C
000763      984 FORMAT( 10X,42HSECOND GROO'    FED LOCATION...       TH2 = ,
000763        1          F12.5,18H  DEGREES      ' TOP)
000763      996 FORMAT( 10X,42HRADIAL INPUT ..ACTION.........    FCGFV = ,
000763        1          F12.5)
000763      998 FORMAT( 10X,42HWICK HEIGHT REL. TO TUBE AXIS.      HREF = ,
000763        1          F12.5,18H  CM                )
000763      990 FORMAT( 10X,42HNO. GROOVES PER CM............      GRVS = ,
000763        1          F12.5,16H  /CM               )
000763      946 FORMAT( 10X,42HPLOT POROSITY.................     IPLOT = ,
000763        1          I2)
000763      947 FORMAT( 10X,42HEXTRA WICK AT BEGINNING.......       XX0 = ,
000763        1          F12.5,16H  CM            )
000763      948 FORMAT( 10X,42HEXTRA WICK ON END.............       XX1 = ,
000763        1          F12.5,16H  CM            )
000763      950 FORMAT( 10X,42HHIGH TOLERANCE ON VOL. DENSITY      HIGH = ,
000763        1          F12.5,16H  PERCENT       )
000763      956 FORMAT( 10X,42HLOW TOLERANCE ON VOL. DENSITY.       LOW = ,
000763        1          F12.5,16H  PERCENT       )
000763           PND=(RHOL-RHOV)*G*(HW/100.)
000770           PRS=2.24E*E*H*ST/((DIAF/100.)*PND)
      C
000776           CALL VSRKS
```

```
         C      VSBKS  CALCULATES THE VAPOR-SPACE BACK STRESS (THE INITIAL STRESS FBO)
         C
000777          XTOT=0.
001000          DO 16 I=1,NQ
001002          XTOT=XTOT+XQ(I)
001005       16 CONTINUE
001010          AB=AW/HW**2
001013          DO 18 I=1,NELEV
001015          ZELEV(I)=XELEV(I)/XTOT
001020          ELEVB(I)=ELEV(I)/HW
001023       18 CONTINUE
001026          DO 20 I=1, NQ
001030          ZQ(I)=XQ(I)/XTOT
001033       20 CONTINUE
001036          NI=XTOT/DX
001041          NIP1=NI+1
001043          DZ=DX/XTOT
         C
         C      CALCULATION OF THE NUMBER OF STEPS TO THE END OF
         C      EACH EVAPORATOR SECTION
         C
001045          II=1
001046          NEV=0
001047          DO 25 I=1,NQ
001051          II=II+XQ(I)/DX
001056          IF(FQ(I).LE.0.) GO TO 25
001060          NEV=NEV+1
001062          IEV(NEV)=II
001064       25 CONTINUE
         C
001067          FNUP=(VISL/RHOL)*(ODCT/HFC)*(XTOT/100.)/
001067         1     (PND*(DIAF/100.)**2*(HW/100.)**2)
         C
         C      CALCULATION OF THE INVERSE CUMULATIVE DISTRIBUTION FUNCTION
         C
001104          IF(LASTEPS.NE.0 .OR. NEPS.NE.0) GO TO 30
001112          Q=1-P
001115          T=SQRT(ALOG(1./(Q*Q)))
```

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```
RUNX COMPILER (VER,2.3M)              09/28/76. 13.24.02.          INPT

001124          FFMI=T-(C0+C1*T+C2*T*T)/(1.+D1*T+D2*T*T+D3*T*T*T)
          C
001141        30 CONTINUE
          C
001141          IF(NEPS.EQ.0) GO TO 101
001142          EPS0=EPSX(1)
001144          J=1
001145          DO 100 I=1,NIP1
001147          X=DX*(I-1)
001153          IF(X.GT.XEPS(J+1)) J=J+1
001160          SAVEPS(I)=EPSX(J)
001163          IF(XEPS(J+1).EQ.XEPS(J)) GO TO 100
001166          SAVEPS(I)=EPSX(J)+(EPSX(J+1)-EPSX(J))*(X-XEPS(J))/
001166         1                    (XEPS(J+1)-XEPS(J))
001201       100 CONTINUE
001204       101 CONTINUE
001204       801 FORMAT(/10X,42HNO.VAPOR FLOW OBSTRUCTIONS....      NOB = ,
001204         1         I2)
          C
001204          WRITE(6,955) ROUGH
001212       955 FORMAT( 10X,42HVAPOR SPACE SURFACE ROUGHNESS.    ROUGH = ,
001212         1         F12.5,16H  CM              )
001212          IF(NOB.EQ.0) GO TO 205
001213          DO 204 I=1,NOB
001215          ZOB(I)=XOB(I)/XTOT
001220       204 CONTINUE
001223          WRITE(6,801) NOB
001231          DO 202 J=1,NOB
001233          WRITE(6,800) J,XOB(J),XKOB(J)
001245       202 CONTINUE
001250       800 FORMAT(10X,21HFLOW OBSTRUCTION NO. ,I2/
001250         1         15X,37HDISTANCE TO OBSTRUCTION..       XOB = ,
001250         2         F12.5,10H  CM      /
001250         3         15X,37HVELOCITY HEADS LOST......      XKOB = ,
001250         4         F12.5)
001250       205 CONTINUE
001250        99 CONTINUE
001250          RETURN
```

RUNX COMPILER (VER.2.3*)   09/28/76. 13.24.02.   INPT

001251   END

RUN COMPILER (VER.2.3P)   09/28/76. 13.24.02.

```
                  FUNCTION PERM(EPSO,EPSS)
          C
          C       PERM  CALCULATES THE DIMENSIONLESS PERMEABILITY OF A PARTIALLY
          C       SATURATED WICK OF OVERALL POROSITY  EPSO  FOR A CRITICAL
          C       POROSITY  EPSS
          C
000005            PERM=1.E-10
000007            IF(EPSS .LE. EPSI) GO TO 70
000012            EPSI=2.*EPSO-1.
000015            DEPS=(EPSS-EPSI)/10.
000020            PERM=0.
000021            DO 50 I=2,10,2
000023            PERM=PERM+4.*FINT(EPSO,EPSI+(I-1)*DEPS)*DEPS/3.
000040         50 CONTINUE
000042            DO 60 I=3,9,2
000044            PERM=PERM+2.*FINT(EPSO,EPSI+(I-1)*DEPS)*DEPS/3.
000061         60 CONTINUE
000063            PERM=PERM+(FINT(EPSO,EPSI)+FINT(EPSO,EPSS))*DEPS/3.
000076         70 CONTINUE
000076            RETURN
000100            END
```

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```
                 SUBROUTINE PLOTEM
         C
         C       PLOTEM  PLOTS THE WICK POROSITY VARIATION
         C
000002           COMMON /PARAM/ EPS,EPSO,PND,GEE,C,NI,NIP1,MW,IGEOM,WKTH,FFIC,
000002          1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002          2               ELEVF(10),H,FNUB,AW,AB,XTOT,DX,DZ,ODTP,QOCT,FB,
000002          3               DIAF,A(8,500),XO(10),ZO(10),PBS,GPVS,PREF,FOGRV,
000002          4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,FPSS,
000002          5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000002          6               NEPS,XEPS(20),EPSX(20),NO,SS,PVS,AAA(40),CCH(40),
000002          7               VELMO,ZCB(10),XKCB(10),YCB(10),TILTS,STRS(40),
000002          8               IPASS,PEFIP,PCLCH,TH1,TH2,IEV(10),NEV,PI,FIP1,
000002          9               IPLOT,XX0,XX1,FPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002           DIMENSION X(504),Y(504),XT(6),YT(6)
000002           DATA (XT(I),I=1,6) /2.0,2.2,2.4,2.6,0.,1./
000002           DATA (YT(I),I=1,6) /5.,5.,5.,5.,0.,1./
         C
000002           NPTS=NIP1+2
000004           NPTSM1=NPTS-1
000006           NPTSP1=NPTS+1
000010           NPTSP2=NPTS+2
         C
         C       SET UP ARRAYS TO BE PLOTTED
         C
000012           DO 50 I=2,NPTSM1
000014           X(I)=(A(1,I-1)+XX0)/2.54
000021           Y(I)=1.-A(5,I-1)
000025        50 CONTINUE
000030           X(NPTS)=X(NPTSM1)+XX1/2.54
000035           Y(NPTS)=Y(NPTSM1)
000040           X(1)=0.
000041           Y(1)=Y(2)
         C
         C       OPEN PLOT FILE USING FORTRAN DEFINED BUFFER
         C
000043           CALL LOOK(50)
```

RUNX COMPILER (VER.2.2M)   09/28/76. 13.24.02.   PLOTER

```
          C
          C      GENERATE SCALING FOR  X AND Y  ARRAYS
          C
000045           CALL SCALE(X,16.,NPTS,1)
000050           Y(NPTSP1)=0.
000052           Y(NPTSP2)=.04
000054           IF(Y(NPTS)*(1.+HIGH/100.) .GT. .4) Y(NPTSP2)=.05
          C
          C      DRAW AXES
          C
000064           CALL AXIS(0,0,18HDISTANCE IN INCHES,-18,16.,0,
000064         1           X(NPTS+1),X(NPTSP2))
000100           CALL AXIS(0,0,23H VOLUME DENSITY OF WICK,23,10.,90.,
000100         1           Y(NPTSP1),Y(NPTSP2))
000114           CALL AXIS(0.,10.,1H ,1,16.,0,
000114         1           X(NPTSP1),X(NPTSP2))
000130           CALL AXIS(16.,0.,1H ,-1,10.,90.,
000130         1           Y(NPTSP1),Y(NPTSP2))
          C
          C      PLOT  X AND Y  ARRAYS
          C
000144           CALL LINE(X,Y,NPTS,1,0,0)
          C
          C      DENOTE THE CONDENSER AND EVAPORATOR ENDS
          C
000150           XC=X(2)/X(NPTSP2)
000153           YC=Y(2)/Y(NPTSP2)
000156           XE=X(NPTSP1)/X(NPTSP2)
000161           YE=Y(NPTSP1)/Y(NPTSP2)
000164           CALL SYMBOL(XC,YC,.4,13,0.,-1)
000170           CALL SYMBOL(XE,YE,.4,13,0.,-1)
          C      ADD TOLERANCE BANDS TO PLOT
          C
000174           IF(HIGH.EQ.0. .AND. LOW.EQ.0.)GO TO 20
000203           DO 10 I=1,NPTS
000205           Y(I)=Y(I)*(1.+HIGH/100.)
000212        10 CONTINUE
000215           CALL LINE(X,Y,NPTS,1,1,74)
```

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```
RUNX COMPILER (VER.2.3M)                 09/28/76. 13.24.02.        PLOTEM

000221          DO 15 I=1,NPTS
000223          Y(I)=Y(I)*(1.-LOW/100.)/(1.+HIGH/100.)
000234       15 CONTINUE
000237          CALL LINE(X,Y,NPTS,1,1,74)
            C
            C   ANNOTATE PLOT
            C
000243          CALL SYMBOL(2.,6.,.2,HD1,0.,60)
000247          CALL SYMBOL(2.,5.5,.2,HD2,0.,60)
000253          IF(HIGH.EQ.0. .AND. LOW.EQ.0.) GO TO 17
000262          CALL LINE(XT,YT,4,1,1,74)
000266          CALL SYMBOL(3.,5.,.2,25HTOLERANCE ON WICK DENSITY,0.,25)
000272       17 CONTINUE
            C
            C   CLOSE PLOT FILE
            C
000272       20 CALL PLOT(0,0,999)
000275          RETURN
000276          END
```

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```
                  SUBROUTINE PROPS(L,I)
         C
         C        THIS ROUTINE COMPUTES FLUID PROPERTIES FROM DATA FITS
         C
000005            COMMON /CPROPS/ XMW,SHPV, 3,PV,RHOL,RHOV,VISL,VISV,XHL,ST,TF
000005            DIMENSION A11(7), A21(7),
000005          1   A31(7), A32(7), A33(7), A34(7), A35(7),
000005          2   A41(7), A42(7), A43(7), A44(7), A45(7),
000005          3   A51(7), A52(7), A53(7), A54(7), A55(7),
000005          4   A61(7), A62(7), A63(7), A64(7), A65(7),
000005          5   A71(7), A72(7), A73(7), A74(7), A75(7),
000005          6   A81(7), A82(7), A83(7), A84(7), A85(7),
000005          7   A91(7), A92(7), A93(7), A94(7), A95(7),
000005          8   A101(7), A102(7), A103(7), A104(7), A105(7),
000005          9   A111(7), A112(7), A113(7), A114(7), A115(7)
         C
         C           WATER (32F<T<400F)
         C
000005            DATA   A11(1),       A21(1)/
000005          *        491.7,        18.016/
000005            DATA   A31(1),       A32(1),       A33(1),       A34(1),       A35(1)/
000005          *    1.3555636,-4.9575766E-5,           0.,           0.,           0./
000005            DATA   A41(1),       A42(1),       A43(1),       A44(1),       A45(1)/
000005          *    1300.5506,-5.7655211E-2,-4.4545066E-4,           0.,           0./
000005            DATA   A51(1),       A52(1),       A53(1),       A54(1),       A55(1)/
000005          *    14.199322,   -6.5267262,   -.81013069,           0.,           0./
000005            DATA   A61(1),       A62(1),       A63(1),       A64(1),       A65(1)/
000005          *    59.491766, 2.5962966E-2,-3.5472126E-5,           0.,           0./
000005            DATA   A71(1),       A72(1),       A73(1),       A74(1),       A75(1)/
000005          *    7.4473136,   -6.0175647,   -.79949642,           0.,           0./
000005            DATA   A81(1),       A82(1),       A83(1),       A84(1),       A85(1)/
000005          *    72.925745,   -.26276099, 5.0332756E-4,-4.4118236E-7, 1.4859626E-10/
000005            DATA   A91(1),       A92(1),       A93(1),       A94(1),       A95(1)/
000005          *   -13.454566,    1.1041377,           0.,           0.,           0./
000005            DATA   A101(1),      A102(1),      A103(1),      A104(1),      A105(1)/
000005          *   -9.6593695,5.3526992E-3,-6.4460291E-6,2.5152227E-9,           0./
000005            DATA   A111(1),      A112(1),      A113(1),      A114(1),      A115(1)/
```

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RUNX COMPILER (VER.2.9M)                    09/20/76. 13.24.02.          PROPS

000005           * -0.437395E-3, 4.117222E-5,-2.230757E-7,2.117195E-10,-7.550F16E-14/
          C
          C         AMMONIA (-107.9F<T<190F)
          C
000005            DATA   A11(2),       A21(2)/
000005           *         391.8,       17.032/
000005            DATA   A31(2),       A32(2),       A33(2),       A34(2),       A35(2)/
000005           *          1.31,          0.,           0.,           0.,          0./
000005            DATA   A41(2),       A42(2),       A43(2),       A44(2),       A45(2)/
000005           *  1.009791E+3,-2.462995E+0, 4.576430E-3,-4.474567E-6,          0./
000005            DATA   A51(2),       A52(2),       A53(2),       A54(2),       A55(2)/
000005           *  1.992774E+1,-4.921740E+0, 2.665C10E-1,-7.570947E-2,          0./
000005            DATA   A61(2),       A62(2),       A63(2),       A64(2),       A65(2)/
000005           *  7.043740E+1,-1.172405E-1, 1.931737E-4,-1.649413E-7,          0./
000005            DATA   A71(2),       A72(2),       A73(2),       A74(2),       A75(2)/
000005           *  1.264098E+2,-1.113379E+1, 2.593120E+0,-4.095769E-1,          0./
000005            DATA   A81(2),       A82(2),       A83(2),       A84(2),       A85(2)/
000005           *  1.597046E+1,-2.496424E-1, 6.623150E-4,-7.941FC5E-7,3.552154E-10/
000005            DATA   A91(2),       A92(2),       A93(2),       A94(2),       A95(2)/
000005           * -1.079390E+2, 1.906C94E+3,-4.727715E+2, 5.354C60E+1,-2.024364E+0/
000005            DATA   A101(2),      A102(2),      A103(2),      A104(2),      A105(2)/
000005           * -4.340186E-1, 3.944716E-3,-6.537242E-6, 3.009435E-9,          0./
000005            DATA   A111(2),      A112(2),      A113(2),      A114(2),      A115(2)/
000005           *  6.424701E-3,-7.504C43E-6,-7.695754E-4,8.023533E-12,          0./
          C
          C         METHYL ALCOHOL (-146F<T<300F)
          C
000005            DATA   A11(3),       A21(3)/
000005           *         922.7,       32.042/
000005            DATA   A31(3),       A32(3),       A33(3),       A34(3),       A35(3)/
000005           *          1.20,          0.,           0.,           0.,          0./
000005            DATA   A41(3),       A42(3),       A43(3),       A44(3),       A45(3)/
000005           *  8.790540E+0,-2.476105E+0, 6.410C24E-3,-7.0C4195E-6, 2.214439E-9/
000005            DATA   A51(3),       A52(3),       A53(3),       A54(3),       A55(3)/
000005           *  1.535411E+1,-4.240035E+0, 3.306130E+0,-1.969CC0E+0, 3.354E5E-1/
000005            DATA   A61(3),       A62(3),       A63(3),       A64(3),       A65(3)/
000005           *  1.099703E+0, 2.032070E-1,-8.417872E-4, 4.7C3277E-7,-4.30C12E-12/
000005            DATA   A71(3),       A72(3),       A73(3),       A74(3),       A75(3)/
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[redacted]

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RUNX COMPILER (VER.2.3M)                09/28/76. 13.24.02.          PROFS

000005        *  1.593164E+1,-2.109096E+1, 1.144326E+1,-4.276643E+0, 5.609908E-1/
000005         DATA   A81(3),      A82(3),      A83(3),      A84(3),      A85(3)/
000005        *  2.285363E+1,-1.153169E-1, 2.303795E-4,-2.155127E-7, 7.55172E-11/
000005         DATA   A91(3),      A92(3),      A93(3),      A94(3),      A95(3)/
000005        *  1.922596E+2,-1.266769E+2, 3.113344E+1,-3.318410E+0, 1.325051E-1/
000005         DATA  A101(3),     A102(3),     A103(3),     A104(3),     A105(3)/
000005        *  9.944433E-2, 2.097417E-4,-6.310697E-7,7.394364E-10,-3.19696E-13/
000005         DATA  A111(3),     A112(3),     A113(3),     A114(3),     A115(3)/
000005        *  5.799525E-3,-1.404494E-5, 1.205620E-8,3.516629E-12,-8.67029E-15/
       C
       C             FREON-21 (-55F<T<305F)
       C
000005         DATA   A11(4),      A21(4)/
000005        *        248.7,       102.-/
000005         DATA   A31(4),      A32(4),      A33(4),      A34(4),      A35(4)/
000005        *        1.175,          0.,          0.,          0.,          0./
000005         DATA   A41(4),      A42(4),      A43(4),      A44(4),      A45(4)/
000005        *  8.667825E+1, 4.636558E-1,-1.631685E-3, 2.056597E-6,-1.018948E-9/
000005         DATA   A51(4),      A52(4),      A53(4),      A54(4),      A55(4)/
000005        *  3.279732E+0, 1.573170E+1,-1.607959E+1, 5.259243E+0,-6.269501E-1/
000005         DATA   A61(4),      A62(4),      A63(4),      A64(4),      A65(4)/
000005        *  1.332756E+2,-3.261757E-1, 1.111655E-3,-1.611728E-6,6.906674E-10/
000005         DATA   A71(4),      A72(4),      A73(4),      A74(4),      A75(4)/
000005        *  8.534322E+1,-1.062575E+2, 1.252681E+2,-4.365662E+1, 5.375463E+0/
000005         DATA   A81(4),      A62(4),      A83(4),      A84(4),      A85(4)/
000005        * -8.347479E+0, 8.530116E-2,-2.757886E-4, 3.643724E-7,-1.753F7E-10/
000005         DATA   A91(4),      A92(4),      A93(4),      A94(4),      A95(4)/
000005        * -1.838536E+3, 1.199366E+3,-2.944711E+2, 3.215076E+1,-1.315728E+0/
000005         DATA  A101(4),     A102(4),     A103(4),     A104(4),     A105(4)/
000005        *  4.750199E-1,-2.403548E-3, 5.713512E-6,-6.391302E-9, 2.65040E-12/
000005         DATA  A111(4),     A112(4),     A113(4),     A114(4),     A115(4)/
000005        * -5.748971E-3, 4.984969E-5,-1.133747E-7,9.235658E-11,-2.25455E-14/
       C
       C             ETHANE (-135F<T<80F)
       C
000005         DATA   A11(5),      A21(5)/
000005        *        101.6,       30.07/
000005         DATA   A31(5),      A32(5),      A32(5),      A34(5),      A25(5)/
```

```
CC0005        *       1.18,         0.,          0.,          0.,          C./
C00005          DATA   A41(5),      A42(5),      A43(5),      A44(5),      A45(5)/
000005        * -4.278934E+3, 4.573254E+1,-1.719481E-1, 2.840439E-4,-1.756889E-7/
000005          DATA   A51(5),      A52(5),      A53(5),      A54(5),      A55(5)/
000005        *  4.513520E+1,-5.803273E+1, 3.388505E+1,-9.165778E+0, 9.1547C4E-1/
000005          DATA   A61(5),      A62(5),      A63(5),      A64(5),      A65(5)/
000005        * -3.433014E+2, 3.901041E+0,-1.478627E-2, 2.451166E-5,-1.518862E-8/
C00005          DATA   A71(5),      A72(5),      A73(5),      A74(5),      A75(5)/
000005        *  9.831080E+1,-1.463731E+2, 6.422928E+1,-2.191841E+1, 2.129803E+0/
000005          DATA   A81(5),      A82(5),      A83(5),      A84(5),      A85(5)/
000005        * -1.723943E+1, 2.931920E-1,-7.953422E-4, 1.385103E-6,-8.90506E-10/
C00005          DATA   A91(5),      A92(5),      A93(5),      A94(5),      A95(5)/
C00005        *  2.099855E+4,-2.017435E+4, 5.085813E+3,-5.697099E+2, 2.392870E+1/
C00005          DATA  A101(5),     A102(5),     A103(5),     A104(5),     A105(5)/
000005        * -1.142960E+0, 1.317096E-2,-5.072525E-5, 8.390294E-8,-5.11860E-11/
000005          DATA  A111(5),     A112(5),     A113(5),     A114(5),     A115(5)/
C00005        *  1.123709E-2,-8.339622E-5, 2.759121E-7,-4.39343E-10,2.651466E-13/
        C
        C             METHANE (-280F<T<-120F)
        C
C0C005          DATA   A11(6),      A21(6)/
000005        *      163.2,        16.04/
000005          DATA   A31(6),      A32(6),      A33(6),      A34(6),      A35(6)/
000005        *       1.32,         0.,          0.,          0.,          0./
000005          DATA   A41(6),      A42(6),      A43(6),      A44(6),      A45(6)/
CC0005        * -1.124091E+3, 2.425142E+1,-1.589307E-1, 4.547110E-4,-4.908714E-7/
C00005          DATA   A51(6),      A52(6),      A53(6),      A54(6),      A55(6)/
C00005        *  1.365684E+0, 8.557617E+0,-3.746570E+0, 5.803347E-1,-3.257158E-2/
000005          DATA   A61(6),      A62(6),      A63(6),      A64(6),      A65(6)/
000005        *  1.449951E+1, 3.848318E-1,-3.223542E-3, 1.076420E-5,-1.353123E-8/
000005          DATA   A71(6),      A72(6),      A73(6),      A74(6),      A75(6)/
C0C005        *  6.381082E+1,-5.445063E+1, 1.637493E+1,-2.759041E+0, 1.547595E-1/
000005          DATA   A81(6),      A82(6),      A83(6),      A84(6),      A85(6)/
000005        * -9.826486E+0, 2.024132E-1,-1.540820E-3, 4.719715E-6,-5.211675E-9/
000005          DATA   A91(6),      A92(6),      A93(6),      A94(6),      A95(6)/
000005        *  9.119631E+3,-6.766529E+3, 1.880522E+3,-2.321585E+2, 1.074409E+1/
C0C005          DATA  A101(6),     A102(6),     A103(6),     A104(6),     A105(6)/
000005        *  3.486478E-1,-1.720959E-3, 3.699297E-7, 1.840747E-8,-3.73323E-11/
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```
000005          DATA  A111(6),      A112(6),      A113(6),      A114(6),      A115(6)/
000005         *  5.412797E-3,-5.463947E-5, 2.856240E-7,-7.817C0E-10,8.146455E-13/
          C
          C         NITROGEN (-340F<T<-250F)
          C
000005          DATA   A11(7),       A21(7)/
000005         *       113.9,       28.016/
000005          DATA   A31(7),       A32(7),       A33(7),       A34(7),       A35(7)/
000005         *        1.40,           0.,           0.,           0.,           0./
000005          DATA   A41(7),       A42(7),       A43(7),       A44(7),       A45(7)/
000005         *  7.649074E+1,-2.305556E-1, 5.317595E-3,-2.340715E-5,           0./
000005          DATA   A51(7),       A52(7),       A53(7),       A54(7),       A55(7)/
000005         *  3.217173E+1,-1.431289E+1, 3.064764E+0,-3.133777E-1, 1.176449E-2/
000005          DATA   A61(7),       A62(7),       A63(7),       A64(7),       A65(7)/
000005         *  7.298716E+1,-3.323232E-1, 2.281469E-3,-7.478632E-6,           0./
000005          DATA   A71(7),       A72(7),       A73(7),       A74(7),       A75(7)/
000005         *  2.102802E+1,-7.503727E+0, 9.613273E-1,-4.861116E-2,           0./
000005          DATA   A81(7),       A82(7),       A83(7),       A84(7),       A85(7)/
000005         * -1.130709E+1, 3.560937E-1,-3.800943E-3, 1.587014E-5,-2.609265E-8/
000005          DATA   A91(7),       A92(7),       A93(7),       A94(7),       A95(7)/
000005         *  1.718670E+4,-1.371991E+4, 4.103945E+3,-5.453515E+2, 2.716624E+1/
000005          DATA  A101(7),      A102(7),      A103(7),      A104(7),      A105(7)/
000005         *  1.178000E-1,-7.992424E-5,-1.401515E-6,           0.,           0./
000005          DATA  A111(7),      A112(7),      A113(7),      A114(7),      A115(7)/
000005         *  1.636031E-3,-3.768939E-6,-4.379371E-8,1.270396E-10,           0./
          C
000005          IF (L.EQ.0) GO TO 20
          C
000006          T2 = T*T
000007          T3 = T2*T
000011          T4 = T2*T2
000013          TR = 1000./T
000015          TR2 = TR*TR
000017          TR3 = TR2*TR
000021          TR4 = TR2*TR2
000023          ALT=ALOG(T)
000027          ALT2=ALT*ALT
000031          ALT3=ALT2*ALT
```

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000033              ALT4=ALT2*ALT2
              C
              C        FLUID PROPERTIES
              C
000035              TF = A11(L)
000037              XMW=A21(L)
000041              SHPV = A31(L)+A32(L)*T+A33(L)*T2+A34(L)*T3+A35(L)*T4
000053              HFG = A41(L)+A42(L)*T+A43(L)*T2+A44(L)*T3+A45(L)*T4
000065              PV = EXP(A51(L)+A52(L)*TR+A53(L)*TR2+A54(L)*TR3+A55(L)*TR4)
000103              RHOL = A61(L)+A62(L)*T+A63(L)*T2+A64(L)*T3+A65(L)*T4
000115              RHOV = EXP(A71(L)+A72(L)*TR+A73(L)*TR2+A74(L)*TR3+A75(L)*TR4)
000133              VISL = EXP(A81(L)+A82(L)*T+A83(L)*T2+A84(L)*T3+A85(L)*T4)
000151              VISV = EXP(A91(L)+A92(L)*ALT+A93(L)*ALT2+A94(L)*ALT3+A95(L)*ALT4)
000167              XKL = A101(L)+A102(L)*T+A103(L)*T2+A104(L)*T3+A105(L)*T4
000201              ST = A111(L)+A112(L)*T+A113(L)*T2+A114(L)*T3+A115(L)*T4
000213              VISV = VISV/4.1697504E8
000215              VISL=VISL/4.1697504E8
000217              RETURN
              C
000220           20 CONTINUE
000220              RETURN
000221              END
```

```
                  SUBROUTINE RECEDE(R,DH,AC,IREC)
          C
          C       RECEDE  CALCULATES THE PARAMETERS FOR A GROOVE WITH A
          C       CIRCULAR MENISCUS
          C
000007            COMMON /PARAM/ EPS,EPSC,PND,GEF,G,NI,NIP1,HW,IGEOM,WKTH,HPIC,
000007           1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000007           2               ELEVB(10),H,FNLB,AW,AB,XTOT,DX,DZ,QDTB,QDOT,FB,
000007           3               DIAF,A(6,500),XG(10),ZG(10),PBS,GRVS,HREF,FCCRV,
000007           4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,EPSS,
000007           5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIMED,
000007           6               NEPS,XEPS(20),EPSX(20),NOB,SS,HVS,AAA(40),DDH(40),
000007           7               VELHD,ZOB(10),XKOB(10),XOB(10),IFLTS,STRS(40),
000007           8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,FI,FFM1,
000007           9               IPLOT,XX0,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000007            COMMON /FPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000007            COMMON /CRVDTA/ ACK,PHIP,SP,CP,TP,SMAX,CMAX,PSIMR,HC,ATRI,PERIF,
000007           1                RMIN,CURV,BOT,FLO,GFAC,VFAC,RWMN,RPD
000007            COMMON /AALFA/ AFIT,BFIT,CFIT,FRF
          C
          C       IREC=1  MEANS MENISCUS ATTACHED TO GROOVE TIPS
          C       IREC=2  MEANS MENISCUS RECEDED FROM TIPS
          C       IREC=3  MEANS MENISCUS TOUCHING THE GROOVE BOTTOM
          C
000007            IF(R.LT.RMIN) GO TO 100
          C
          C       MENISCUS ATTACHED TO GROOVE TIPS
          C
000012            SPSI=(W/100.)/(2.*R)
000015            CPSI=SQRT(1.-SPSI*SPSI)
000024            PSIR=ATAN(SPSI/CPSI)
000033            ACON=90.-PHI-(PSIR/RPD)
000037            CALL ALFA(ACON)
000044            AC=((W/100.)/2.)*(((W/100.)/(2.*TF))+R*CPSI)-PSIR*R*R
000057            AC=AC-ATRI
000061            DH=4.*AC/PERIF
000064            TEST=R*(1.-CPSI)
```


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```
                  SUBROUTINE RUNGE(Y,YP,DZ)
            C
            C     RUNGE  TAKES ONE INTEGRATION STEP BY THE RUNGE-KUTTA METHOD
            C
000006            DIMENSION Y(5),YP(5),YP1(5),YP2(5),YP3(5),YP4(5),YD(5)
000006            DO 1 I=1,5
000010            YP1(I)=YP(I)
000013          1 YD(I)=Y(I)+YP1(I)*DZ/2.
000022            CALL DERIV(YP2,YD)
000026            DO 2 I=1,5
000030          2 YD(I)=Y(I)+YP2(I)*DZ/2.
000037            CALL DERIV(YP3,YD)
000043            DO 3 I=1,5
000045          3 YD(I)=Y(I)+YP3(I)*DZ
000053            CALL DERIV(YP4,YD)
000057            DO 4 I=1,5
000061          4 Y(I)=Y(I)+(YP1(I)+2.*YP2(I)+2.*YP3(I)+YP4(I))*(DZ/6.)
000076            CALL DERIV(YP,Y)
000102            RETURN
000103            END
```

```
000067          IREC=1
000070          IF(TEST.GE.(DEPTH/100.)) IREC=2
000075          RETURN
          C
000076      100 CONTINUE
          C     MENISCUS RECEDED INTO GROOVE
000076          IREC=2
000077          ACON=ANGWET
000101          CALL ALFA(ACON)
000106          PERI=2.*R*SMAX/SP-BCT
000113          AC=R*SMAX*(R*SMAX/TP+R*CMAX)-PSIMR*R*R
000123          AC=AC-ATP1
000125          DH=4.*AC/PERI
000130          TEST1=R*SMAX/TP-HG
000134          TEST2=R*(1.-CMAX)
000137          IF(TEST2.GE.TEST1) IREC=3
000143          RETURN
000144          END
```

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```
                  SUBROUTINE VSBKS
            C
            C     VSBKS  CALCULATES THE VAPOR-SPACE BAK STRESS, WHICH SETS
            C     THE INITIAL STRESS  PBO
            C
000002            COMMON /PARAM/ EPS,EPSC,PND,GEE,G,NI,NIP1,HW,IGEOM,NKTH,HFIC,
000002           1               NC,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000002           2               ELEVP(10),H,FNUP,AW,AB,XTOT,DX,DZ,QDTO,QDOT,FB,
000002           3               DIAF,A(8,500),XC(10),ZC(10),PBS,GPVS,HWEF,FCGHV,
000002           4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IPK,NH,EPSS,
000002           5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPFD,
000002           6               NEPS,XEPS(20),EPSX(20),NJB,SS,HVS,AAA(40),CCH(40),
000002           7               VELHC,ZOB(10),XKOB(10),XJB(10),IFLTS,STPS(40),
000002           8               IPASS,PFFIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000002           9               IPLOT,XXO,XX1,EFSMIN,HIGH,LOW,HD1(6),HD2(6)
000002            COMMON /CPROPS/ XMW,SHRV,HFG,FV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002            DIMENSION SA(3),SB(3),SG(3),SN(3)
000002            DATA (SA(I),I=1,3) /.6W,1.5,2.2447/,
000002           1     (SB(I),I=1,3) /.40,.50,.50/,
000002           2     (SG(I),I=1,3) /1.5,1.0,1.5/,
000002           3     (SN(I),I=1,3) /1.9,1.2,1./
            C
000002            IF(GEE.EQ.0.) GO TO 10
000003            PBO=(ST/(HPIL/200.)+(RHOL-RHOV)*GEE*G*HW/100.)/PND
000015            B=1./(4.*ST/((RHOL-RHOV)*GEE*G*(DIAVS/100.)**2))
000026            J=IGEOM+1
000030            YTR=1./B+(SA(J)/B**SB(J))*(1.-SN(J)*EXP(-SG(J)*SQRT(B)))
000051            YT=YTR*DIAVS/100.
000054            PBO1=(YT+(HW-HVS)/100.)*(RHOL-RHOV)*GEE*G/PND
000066            IF(PBO.LT.PBO1) PBO=PBO1
000071            RETURN
000072         10 PBO=(4.*ST/(DIAVS/100.))/PND
000077            RETURN
000100            END
```

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```
                 SUBROUTINE WET(TSTGN,R1,R2,TL1,TL2)
           C
           C     WET  INTEGRATES ALONG THE GROOVE FROM  TH1  AND  TH2  AND
           C     REPORTS LOCATIONS  TL1  AND  TL2  WHERE DRY-UP OCCURS
           C
000010           COMMON /PARAM/ EPS,EPSO,PNO,GFE,G,NI,NIP1,HW,IGEOM,WKTH,HPIG,
000010          1               NG,FC(10),NELEV,XELEV(10),ZELEV(10),ELEV(10),
000010          2               ELEVB(10),H,FNLB,AW,AB,XTCT,DX,DZ,CDTB,CDCT,PB,
000010          3               DIAF,A(8,500),XC(10),ZC(10),PBS,GRVS,HREF,FCGRV,
000010          4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMH,NH,EPSS,
000010          5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPEC,
000010          6               NEPS,AEPS(20),EPSX(20),NOP,SS,HVS,AAA(40),CCH(40),
000010          7               VELHO,ZCB(10),XCB(10),XOH(10),IFLTS,STPS(40),
000010          8               IPASS,PERIM,ROUGH,TH1,TH2,IEV(10),NEV,PI,FFM1,
000010          9               IPLOT,XXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000010           COMMON /PROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000010           COMMON /GRVDTA/ ACR,PHIR,SH,CP,TF,SPAN,CMAX,PSIMR,HG,ATRI,PERIF,
000010          1                RMIN,CURV,BCT,FLC,GFAC,VFAC,FWPN,RPD
000010           COMMON /ALFA/ AFIT,BFIT,CFIT,FRF
           C
000010           NT1=TSTGN-TH1
000013           IF(NT1.EQ.0) NT1=1
000015           XT1=NT1
000017           DT1=(TSTGN-TH1)/XT1
000022           NT2=TH2-TSTGN
000025           IF(NT2.EQ.0)NT2=1
000027           XT2=NT2
000031           DT2=(TH2-TSTGN)/XT2
000034           FLO1=FLO*(TSTGN-TH1)/(TH2-TH1)
000041           FLO2=FLO*(TH2-TSTGN)/(TH2-TH1)
000045           DFLO1=FLO1/XT1
000047           DFLO2=FLO2/XT2
000051           P1=1./R1
000053           P2=1./R2
000055           N=NT1
000057           P=P1
000061           FFLO=FLO1
```


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```
000063          DFLO=DFLO1
000065          DT=DT1
000067          T=TH1
000071          IFLAG=0
000072      100 CONTINUE
000072          DO 101 I=1,N
000074          P=1./R
000076          CALL RECEDE(R,DH,AC,IREC)
000104          IF(IREC.EQ.3) GO TO 102
000106          DPDT=-GFAC*SIN(RPD*T)+FRF*VFAC*FFLO/(AC*DH**2)
000125          DPDT=DPDT*RPD
000127          P=P+DPDT*DT
000132          FFLO=FFLO-DFLO
000134          T=T+DT
000136      101 CONTINUE
        C
000141      102 CONTINUE
000141          IFLAG=IFLAG+1
000143          IF(IFLAG.EQ.2) GO TO 103
000145          TL1=T
000146          N=NT2
000150          P=P2
000152          FFLO=-FLO2
000154          DFLO=-DFLO2
000156          DT=-DT2
000160          T=TH2
000162          GO TO 100
000163      103 CONTINUE
000163          TL2=T
000164          RETURN
000165          END
```

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```
                SUBROUTINE WRT
          C
          C     WRT  WRITES THE RESULTS
          C
000002          COMMON /PARAM/ EPS,EPSO,FND,CEF,G,NI,NIP1,HW,IGEOM,WKTH,HFIP,
000002         1               NG,FC(10),NELEV,XELEV(10),ZELEV(10),FLEV(10),
000002         2               ELEVB(10),H,FNLB,AW,AB,XTCT,DX,DZ,DDTB,DDCT,HB,
000002         3               DIAF,A(8,500),XC(10),ZC(10),PBS,GRVS,HREF,FCCPV,
000002         4               NCASE,LASTEPS,SAVEPS(500),IFAIL,PBO,IMN,NH,EPSS,
000002         5               NVS,AVS,VFF,DIAVS,W,DEPTH,PHI,ANGWET,S,IPRIPED,
000002         6               NEPS,XEPS(20),EPSX(20),NOP,SS,HVS,AAA(40),CDH(40),
000002         7               VELHD,ZOB(10),XROB(10),XOB(10),IFLTS,STRS(40),
000007         8               IPASS,FLHIP,ROLGH,TH1,TH2,IEV(10),NEV,PI,FIP1,
000002         9               IPLOT,XXO,XX1,EPSMIN,HIGH,LOW,HD1(6),HD2(6)
000002          COMMON /PROPS/ XMW,SHPV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000002          DIMENSION REVP(10),X(11),WW(11),WP(11)
000002          IMK=2
000003          GMASS=A(4,NIP1)*(AW/1000.)*RHOL*(XTCT/100.)*1000.
000014          CDT=CDTP*LDCT
000016          VVAP=(CDT/HFG)/(FLOAT(NVS)*(AVS*1.E-4)*RHOV)
000024          REV=VVAP*(DIAVS/100.)/(VISV/RHOV)
000031          VELHD=100.*(.5*RHOV*VVAP**2)/((RHOL-RHOV)*G)
000040          IF(REV.LT.RCRIT) GO TO 61
000043          X(1)=4.
000045          DO 51 I=1,10
000047          P1=X(I)
000051          P2=2.*ALOG10(2.51*X(I)/REV+ROLGH/(3.7*DIAVS))
000064          WW(I)=P1+P2
000067          TEST=-P1/P2
000071          WP(I)=1.+(5.02/REV)/(2.51*X(I)/REV+ROLGH/(3.7*DIAVS))
000105          X(I+1)=X(I)-WW(I)/WP(I)
000111          F=1./X(I+1)**2
000114          IF(ABS(TEST-1.) .LT. .001) GO TO 61
000121       51 CONTINUE
000123       61 CONTINUE
000123          DO 20 I=1,NG
000125          VVAPR=(FC(I)*CDT/HFG)/(RHOV*(XC(I)/100.)*(NVS*FLRIM/100.))
```

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```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.         WRT

000140          REVR(I)=VVAPR*(DIAVS/2CC.)/(VISV/RHOV)
0001-7       20 CONTINUE
000152          DO 50 J=1,NIP1
000154          A(1,J)=XTOT*A(1,J)
000160          A(2,J)=A(2,J)*HW
000163          IF(A(1,J).GE.XELEV(IPK)) IPK=IPK+1
000172          A(7,J)=(ELEV(IPK-1)+(A(1,J)-XELEV(IPK-1))*(ELEV(IPK)-ELEV(IPK-1))
000172         1        /(XELEV(IPK)-XELEV(IPK-1)))*GEE
000210          IF(GEE .EQ. 0.) A(6,J)=0.
000213          SAVEPS(J)=A(5,J)
000216          A(8,J)=A(8,J)*HW
000221       50 CONTINUE
000224          WRITE(6,960)
000230          WRITE(6,962) QCT,GMASS,REV,VELHD
000244          IF(REV .GT. 23CC.) WRITE(6,967) F
000254          WRITE(6,961)
000260          DO 60 I=1,NC
000262          WRITE(6,963) I,REVR(I)
000272       60 CONTINUE
000275          WRITE(6,964)
000301          DO 90 J=1,NIP1
000303          WRITE(6,966) A(1,J),A(2,J),A(6,J),A(5,J),A(7,J),A(8,J)
000332       90 CONTINUE
000335      960 FORMAT(1H1,4X,15HFINAL SOLUTION //)
000335      962 FORMAT(10X,40HTHE MAXIMUM HEAT-TRANSFER RATE IS....... ,
000335         1        F12.5,7H  WATTS/
000335         2        10X,40HTHE TOTAL LIQUID IN WICK IS............. ,
000335         3        F12.5,7H  GRAMS/
000335         4        10X,40HTHE VAPOR REYNOLDS NUMBER IS............ ,
000335         5        F12.1/
000335         6        10X,40HTHE MAX. VAPOR VELOCITY HEAD IS......... ,
000335         7        F12.5,9H  CM LIQ.)
000335      967 FORMAT(10X,40HTHE MAX. TURBULENT FRICTION FACTOR IS.. ,
000335         1        F12.5/)
000335      961 FORMAT(10X,33HTHE RADIAL REYNOLDS NUMBERS ARE: )
000335      963 FORMAT(15X,16HFOR SECTION NO. ,I2,17H................ ,
000335         1        F12.5)
000335      964 FORMAT(///
```

```
RUNX COMPILER (VER.2.3M)                    09/28/76. 13.24.02.         ART

000335       1   1FX,8HDISTANCE,8X,6HSTRESS,7X,11HSTATIC HEAD,6X,8HPOROSITY,
000335       2   5X,12H SATURATION ,3X,14HVAPOR PRESSURE/17X,4H(CM),9X,
000335       1   9H(CM LIQ.),6X,9H(CM LIQ.),36X,9H(CM LIQ.)///)
000339    966 FORMAT(10X,6E13.4)
000333        RETURN
000336        END
```

20263-6026-RU-1

A.2 PROGRAM FILLET

The mathematical methods employed by FILLET are described in Reference (2). The first part of the program computes a separate table, for each type of fillet or puddle that can exist in the heat pipe, of the area, free perimeter, wetted perimeter and hydraulic diameter for various values of stress. By statement 500 this is accomplished. The rest of the program manipulates the data into a usable form. For the fillet that forms at the bottom of a vertical wick and the puddle, the values of stress in the tables does not increase monotonically. Subroutine REARNG rearranges these tables for increasing stress.

The next step is to obtain total values for the area and hydraulic diameter for all fillets and puddles in the heat pipe. For a specified value of stress, subroutine INTER interpolates the tables, and the areas and wetted perimeters are summed from which a total hydraulic diameter is calculated. This is done for a range of values of stress to construct a table of total area and hydraulic diameter as a function of stress. This table is then written on TAPE 7.

```
NX COMPILER (VER.2.3M)            09/28/76. 13.05.23.

                PROGRAM FILLET (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
          C
          C     FILLET CALCULATES THE MENISCUS SHAPE, AREA, FREE PERIMETER,
          C     WETTED PERIMETER AND HYDRAULIC DIAMETER FOR FILLETS IN A
          C     SLAB-WICK HEAT PIPE AND A BILGE IN A CIRCULAR TUBE.
          C
00004           NAMELIST /FILLETD/ HPID,WKTH,RHO,ST,GEE,IGEOM,TKELVN,LIO
          C
          C     R  IS THE TUBE RADIUS IN CM
          C     T  IS THE WICK THICKNESS IN CM
          C     RHO  IS THE DENSITY DIFFERENCE BETWEEN LIQUID AND VAPOR
          C          IN KG/M**3
          C     ST  IS THE SURFACE TENSION IN N/M
          C     GEE IS THE GRAVITATIONAL ACCELERATION IN STANDARD GRAVITIES
          C     LIO  IS THE LIQUID PARAMETER
          C     TKELVN IS THE TEMPERATURE
          C
          C     ICNFG = 1    FOR A VERTICAL WICK
          C           = 2    FOR A HORIZONTAL WICK
          C           = 3    FOR NO WICK (BILGE ONLY)
          C
00004           DIMENSION STRESS1(80),STRESS2(40),STRESS3(40),STRESS4(40),
00004          1          STRESS5(40),STRESS6(80),SF1(80),SF2(40),SF3(40),
00004          2          SF4(40),SF5(40),SF6(80),D1(80),D2(40),D3(40),D4(40),
00004          3          D5(40),D6(80),A1(80),A2(40),A3(40),A4(40),A5(40),
00004          4          A6(80),SW1(80),SW2(40),SW3(40),SW4(40),SW5(40),SW6(80),
00004          5          DDH(80),AAA(80),STRS(80)
          C
00004           COMMON /CPRCPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
          C
          C     DIMENSIONLESS PARAMETERS
          C
00004           READ FILLETD
00007           IF(LIO.EQ.0) GO TO 10
00010           TRANK=TKELVN*1.8
00012           CALL PROPS(LIO,TRANK)
00014           RHO=.4536*3.281**3*(RHOL-RHOV)
```

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```
      ST=4.448*3.281*ST
C
   10 G=9.80
      ICNFG=IGEOM
      IF(IGEOM.EQ.0) ICNFG=2
      A=SQRT(2.*ST/(RHO*GEE*G))
      R=HPID/2.
      T=WKTH
      RB=(R/100.)/A
      TB=(T/100.)/A
      PI=3.141592654
      DALPHA=PI/180.
C
C     SET RANGE FOR THE STRESS  H  AT THE INTEGRATION STARTING POINT
C
      HO=1./(10.*RB)
      HF=20.
      NH=40.
      GG=(HF/HO)**(1./(NH-1))
C
C     CALCULATION OF AREA, WETTED PERIMETER, FREE PERIMETER,
C     HYDRAULIC DIAMETER AND STRESS AT EACH VALUE OF  H.
C
      DO 500 K=1,NH
      H=HO*GG**(K-1)
C
C     TOP FILLET -- WICK VERTICAL (CASE 3)
C
      IF(ICNFG.NE.1) GO TO 44
      X=-TB/2.
      ALPHA=PI/2.
      Y=H
      XO=X
      YO=Y
      ALPHAO=ALPHA
      AA=0.
      SF=0.
      DO 20 I=1,180
```


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```
00130          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,X0,Y0,ALPHAO)
00141          CRIT=X-RB*SIN(ALPHA)
00146          IF(CRIT .GE. 0.) GO TO 22
00150       20 CONTINUE
00152          GO TO 24
00153       22 W0=-TB/2.
00155          W1=0.
00156          W2=X
00160          W3=W0
00162          V0=H
00164          V1=Y+RB*COS(ALPHA)
00171          V2=Y
00173          V3=V1+SQRT(RB*RB-W0*W0)
      C
      C        ELIMINATE UNSTABLE SOLUTIONS
      C
000201         IF(STRESS3(K-1).NE.0. .AND. V1.GT.STRESS3(K-1)) GO TO 26
000211         STRESS3(K-1)=0.
000213         A3(K-1)=0.
000215         SF3(K-1)=0.
000217         SW3(K-1)=0.
000221         D3(K-1)=0.
000223      26 CALL SANF(A3(K),PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
000236         STRESS3(K)=V1
000240         SF3(K)=SF
000242         SW3(K)=PW+V3-V0
000246         D3(K)=4.*A3(K)/SW3(K)
      C
      C        LOWER AND UPPER BOTTOM  FILLETS -- WICK VERTICAL (CASES 1 & 2)
      C
000252      24 X=TB/2.
000254         ALPHA=-PI/2.
000256         Y=H
000260         X0=X
000262         Y0=Y
000264         IF(Y0.LE.1.0) GO TO 44
000267         ALPHA0=ALPHA
000271         AA=0.
```

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```
00272              SF=0.
00273              IFLAG=0
00274              DO 30 I=1,360
00276              CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
000307             CRIT=X-RB*SIN(ALPHA)
000314             IF(IFLAG.EQ.1) GO TO 28
000316             IF(CRIT .LE. 0. .AND. ALPHA .LT. PI/2.) GO TO 34
000330          28 IF(CRIT .GT. 0. .AND. I .EQ. 180) GO TO 44
000341             IF(CRIT .GT. 0. .AND. ALPHA .GE. PI/2.) GO TO 34
000353          29 CONTINUE
000353          30 CONTINUE
000355          34 WO=TB/2.
000357             W1=0.
000360             W2=X
000362             W3=WO
000364             VO=H
000366             V1=Y+RB*COS(ALPHA)
000373             V2=Y
000375             V3=V1-SQRT(RB*RB-WO*WO)
000403             CALL SANF(AA1,PW,WO,W1,W2,W3,VO,V1,V2,V3,AA)
000416             K1=K
000420             IF(IFLAG .EQ. 1) K1=K+NH
000424             IF(IFLAG.EQ.1 .AND. IO1.EQ.1) GO TO 44
000433             IF(IFLAG.EQ.1 .AND. STRESS1(K1-1).EQ.0.) GO TO 35
000444             IF(IFLAG.EQ.1 .AND. V1.GT.STRESS1(K1-1)) IO1=1
000457             IF(IFLAG.EQ.1 .AND. IO1.EQ.1) GO TO 44
000466          35 CONTINUE
000466             A1(K1)=AA1
000470             STRESS1(K1)=V1
000472             SW1(K1)=PW+VO-V3
000476             SF1(K1)=SF
000500             D1(K1)=4.*A1(K1)/SW1(K1)
000504             IF(IFLAG .EQ. 1) GO TO 44
000506             IFLAG=1
000507             GO TO 29
           C
           C       LOWER FILLET -- HORIZONAL WICK (CASE 4)
           C
```


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```
00510      44 IF(ICNFG.NE.2) GO TO 68
00512         X=0.
00513         Y=H
00515         ALPHA=PI
00517         X0=X
00521         Y0=Y
00523         IF(Y0.LE.2.) GO TO 58
00526         ALPHA0=ALPHA
00530         AA=0.
00531         SF=0.
00532         DO 50 I=1,180
00534         CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,X0,Y0,ALPHA0)
00545         CRIT=RB*COS(ALPHA)+Y-H-TB/2.
00555         IF(CRIT .GE. 0.) GO TO 52
000557     50 CONTINUE
000561        GO TO 58
000562     52 W0=0.
000563        W1=X-RB*SIN(ALPHA)
000570        W2=X
000572        W3=W1-SQRT(RB*RB-TB*TB/4.)
000601        V0=H
000603        V1=H+TB/2.
000606        V2=Y
000610        V3=H
000612        CALL SANF(A4(K),PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
000625        STRESS4(K)=V1
000627        SF4(K)=SF
000631        SW4(K)=PW+(W0-W3)
000635        D4(K)=4.*A4(K)/SW4(K)
        C
        C     UPPER FILLET -- WICK HORIZONTAL (CASE 5)
        C
000641     58 X=0.
000642        Y=H
000644        ALPHA=0.
000645        X0=X
000647        Y0=Y
000651        ALPHA0=ALPHA
```

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```
000653          AA=0.
000654          SF=0.
000655          DO 60 I=1,180
000657          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,X0,Y0,ALPHA0)
000670          CRIT=Y+RB*COS(ALPHA)-H+TB/2.
000701          IF(CRIT .LE. 0.) GO TO 62
000703       60 CONTINUE
000705          GO TO 68
000706       62 W0=0.
000707          W1=X-RB*SIN(ALPHA)
000714          W2=X
000716          W3=W1+SQRT(RB*RB-TB*TB/4.)
000725          V0=H
000727          V1=H-TB/2.
000732          V2=Y
000734          V3=H
000736          CALL SANF(A5(K),PW,W0,W1,W2,W3,V0,V1,V2,V3,AA)
000751          STRESS5(K)=V1
000753          SF5(K)=SF
000755          SW5(K)=PW+W3-W0
000761          D5(K)=4.*A5(K)/SW5(K)
            C
            C   BILGE -- NO WICK (CASE 6 ^ 7)
            C
000765       68 X=0.
000766          ALPHA=0.
000767          Y=H
000771          X0=X
000773          Y0=Y
000775          ALPHA0=ALPHA
000777          AA=0.
001000          SF=0.
001001          IFLAG=0
001002          IF(1./(2.*Y0) .LE. RB .AND. IFLAG .EQ. 0) IFLAG=1
001016          DO 70 I=1,180
001020          CALL SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,X0,Y0,ALPHA0)
001031          CRIT=X-RB*SIN(ALPHA)
001036          IF(IFLAG.EQ.1) GO TO 65
```

```
001040          IF(CRIT .LE. C. .AND. ALPHA .LT. PI/2.) GO TO 74
001052       65 IF(CRIT .GT. O. .AND. I .EQ. 90) GO TO 84
001063          IF(CRIT .GT. O. .AND. ALPHA .GT. PI/2.) GO TO 74
001075       69 CONTINUE
001075       70 CONTINUE
001077       74 WO=O.
001100          W1=O.
001101          W2=X
001103          W3=O.
001104          VO=H
001106          V1=Y+RB*COS(ALPHA)
001113          V2=Y
001115          V3=V1-RB
001117          CALL SANF(AA6,PW,WO,W1,W2,W3,VO,V1,V2,V3,AA)
001132          K1=K
001134          IF(IFLAG.EQ.1) K1=K+NH
001140          IF(IFLAG.EQ.1 .AND. IO6.EQ.1) GO TO 84
001147          IF(IFLAG.EQ.1 .AND. STRESS6(K1-1).EQ.O.) GO TO 75
001160          IF(IFLAG.EQ.1 .AND. V1.GT.STRESS6(K1-1)) IO6=1
001173          IF(IFLAG.EQ.1 .AND. IO6.EQ.1) GO TO 84
001202       75 CONTINUE
001202          A6(K1)=2.*AA6
001205          STRESS6(K1)=V1
001207          SW6(K1)=2.*PW
001212          SF6(K1)=2.*SF
001215          D6(K1)=4.*A6(K1)/SW6(K1)
001221          IF(IFLAG.EQ.1) GO TO 84
001223       78 IFLAG=1
001224          GO TO 69
001225       84 CONTINUE
001225      500 CONTINUE
001230          CALL REARNG(STRESS1,NH)
001232          CALL REARNG(SF1,NH)
001234          CALL REARNG(SW1,NH)
001236          CALL REARNG(A1,NH)
001240          CALL REARNG(STRESS6,NH)
001242          CALL REARNG(SF6,NH)
001244          CALL REARNG(SW6,NH)
```

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```
001246          CALL REARNG(A6,NH)
001250          N=2*NH
001252          DO 600 I=1,NH
001254          STRS(I)=HO*GG**(I-1)
001263          IF(ICNFG.NE.1) GO TO 507
001265          CALL  INTER(A3,STRESS3,NH,STRS(I),YA3)
001271          CALL  INTER(SW3,STRESS3,NH,STRS(I),YSW3)
001275          CALL  INTER(A1,STRESS1,N,STRS(I),YA1)
001301          CALL  INTER(SW1,STRESS1,N,STRS(I),YSW1)
001305          AAA(I)=2.*(YA1+YA3)*A*A
001312          IF(AAA(I).EQ.0.) GO TO 600
001314          SSW=2.*(YSW3+YSW1)*A
001320          DDH(I)=4.*AAA(I)/SSW
001324          STRS(I)=STRS(I)*A
001327          GO TO 600
001330      507 IF(ICNFG.EQ.3) GO TO 517
001332          CALL  INTER(A4,STRESS4,NH,STRS(I),YA4)
001336          CALL  INTER(SW4,STRESS4,NH,STRS(I),YSW4)
001342          CALL  INTER(A5,STRESS5,NH,STRS(I),YA5)
001346          CALL  INTER(SW5,STRESS5,NH,STRS(I),YSW5)
001352      517 CALL  INTER(A6,STRESS6,N,STRS(I),YA6)
001356          CALL  INTER(SW6,STRESS6,N,STRS(I),YSW6)
001362          AAA(I)=(2.*(YA4+YA5)+YA6)*A*A
001370          IF(AAA(I).EQ.0.) GO TO 600
001372          SSW=(2.*(YSW4+YSW5)+YSW6)*A
001377          DDH(I)=4.*AAA(I)/SSW
001403          STRS(I)=STRS(I)*A
001406      600 CONTINUE
        C
001411          WRITE(7) NH,(STRS(I),I=1,NH),(AAA(I),I=1,NH),(DDH(I),I=1,NH)
        C
        C       THE OUTPUT IS A TABLE OF AREA IN M**2 AND HYDRAULIC
        C       DIAMETER IN M AS A FUNCTION OF STRESS AT THE TUBE CENTER
        C       IN M OF LIQUID.
        C
001441          STOP
001443          END
```


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```
RUNX COMPILER (VER.2.3M)                         09/28/76. 13.05.23.

                SUBROUTINE DRV(ALPHA,DX,DS,DA,X,Y,XO,YO,ALPHAO)
000014          Y=SQRT(YO*YO+COS(ALPHAO)-COS(ALPHA))
000040          DX=COS(ALPHA)/(2.*Y)
000050          DS=1./(2.*Y)
000052          DA=ABS((X-XO)*SIN(ALPHA)-(Y-YO)*COS(ALPHA))/(4.*Y)
000075          RETURN
000076          END
```

RUNX COMPILER (VER.2.3M)   09/28/76. 13.05.23.

```
                 SUBROUTINE INTER(F,X,N,XX,Y)
          C
          C      SUBROUTINE  INTER  INTERPOLATES THE CALCULATIONED DATA
          C
000010           DIMENSION F(1),X(1)
          C
000010           XMIN=1.E6
000012           XMAX=-1.E6
000014           DO 40 I=1,N
000016           IF(X(I).EQ.0.) GO TO 40
000020           IF(X(I).GE.XMIN) GO TO 30
000024           XMIN=X(I)
000026           IMIN=I
000030        30 IF(X(I).LE.XMAX) GO TO 40
000034           XMAX=X(I)
000036           IMAX=I
000040        40 CONTINUE
000043           IF(XX.GT.XMIN) GO TO 50
000047           Y=F(IMIN)
000051           RETURN
000052        50 IF(XX.LT.XMAX) GO TO 60
000055           Y=0.
000056           RETURN
000057        60 CONTINUE
000057           F2=0.
000060           X2=0.
000061           DO 70 I=1,N
000063           IF(X(I).EQ.0.) GO TO 70
000065           F1=F2
000067           F2=F(I)
000071           X1=X2
000073           X2=X(I)
000075           IF(X2.GT.XX .AND. X1.LT.XX) GO TO 80
000105        70 CONTINUE
000110        80 Y=F1+(F2-F1)*(XX-X1)/(X2-X1)
000117           RETURN
000120           END
```

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RUNX COMPILER (VER.2.3M)   09/28/76. 13.05.23.

```
                  SUBROUTINE REARNG(A,NH)
          C
          C       REARNG  REARRANGES THE PARAMETERS FOR THE BILGE AND
          C       BOTTOM FILLET/VERTICAL WICK FOR INCREASING STRESS
          C
000005            DIMENSION A(60), DUMMY(60)
000006            DO 10 I=1,NH
000007            I1=NH+I
000011            DUMMY(I)=A(2*NH-I+1)
000014            DUMMY(I1)=A(I)
000017         10 CONTINUE
000022            N=NH*2
000023            DO 20 I=1,N
000025            A(I)=DUMMY(I)
000030         20 CONTINUE
000033            RETURN
000034            END
```

RUNX COMPILER (VER.2.3M)   09/28/76. 13.05.23.

```
                 SUBROUTINE PROPS(L,T)
          C
          C        THIS ROUTINE COMPUTES FLUID PROPERTIES FROM DATA FITS
          C
000005           COMMON /CPROPS/ XMW,SHRV,HFG,PV,RHOL,RHOV,VISL,VISV,XKL,ST,TF
000005           DIMENSION A11(7), A21(7),
000005          1  A31(7), A32(7), A33(7), A34(7), A35(7),
000005          2  A41(7), A42(7), A43(7), A44(7), A45(7),
000005          3  A51(7), A52(7), A53(7), A54(7), A55(7),
000005          4  A61(7), A62(7), A63(7), A64(7), A65(7),
000005          5  A71(7), A72(7), A73(7), A74(7), A75(7),
000005          6  A81(7), A82(7), A83(7), A84(7), A85(7),
000005          7  A91(7), A92(7), A93(7), A94(7), A95(7),
000005          8  A101(7), A102(7), A103(7), A104(7), A105(7),
000005          9  A111(7), A112(7), A113(7), A114(7), A115(7)
          C
          C          WATER (32F<T<400F)
          C
000005           DATA   A11(1),       A21(1)/
000005          *       491.7,        18.016/
000005           DATA   A31(1),       A32(1),        A33(1),        A34(1),        A35(1)/
000005          *    1.3555636,-4.957576E-5,            0.,            0.,            0./
000005           DATA   A41(1),       A42(1),        A43(1),        A44(1),        A45(1)/
000005          *    1209.5506,-5.705515E-2,-4.454586E-4,             0.,            0./
000005           DATA   A51(1),       A52(1),        A53(1),        A54(1),        A55(1)/
000005          *    14.199322,  -6.5267262,   -.81013069,            0.,            0./
000005           DATA   A61(1),       A62(1),        A63(1),        A64(1),        A65(1)/
000005          *    58.491766, 2.566296E-2,-3.547212E-5,             0.,            0./
000005           DATA   A71(1),       A72(1),        A73(1),        A74(1),        A75(1)/
000005          *    7.4432132,  -6.0175647,   -.79940952,            0.,            0./
000005           DATA   A81(1),       A82(1),        A83(1),        A84(1),        A85(1)/
000005          *    52.825785,  -.26276099, 5.033270E-4,-4.411623E-7, 1.46562E-10/
000005           DATA   A91(1),       A92(1),        A93(1),        A94(1),        A95(1)/
000005          *    -10.66486,   1.1041567,            0.,            0.,            0./
000005           DATA  A101(1),      A102(1),       A103(1),       A104(1),       A105(1)/
000005          *   -1.0535655,5.3522992E-3,-6.446050E-6,2.5152327E-9,            0./
000005           DATA  A111(1),      A112(1),       A113(1),       A114(1),       A115(1)/
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```
000005       * -9.437350E-3, 9.717223E-5,-2.230757E-7,2.117395E-10,-7.530815E-14/
        C
        C          AMMONIA (-107.9F<T<190F)
        C
000005         DATA   A11(2),       A21(2)/
000005       *        351.8,        17.032/
000005         DATA   A31(2),       A32(2),       A33(2),       A34(2),       A35(2)/
000005       *         1.31,           0.,           0.,           0.,           0./
000005         DATA   A41(2),       A42(2),       A43(2),       A44(2),       A45(2)/
000005       *  1.093251E+3,-2.482955E+0, 4.976430E-3,-4.474967E-6,           0./
000005         DATA   A51(2),       A52(2),       A53(2),       A54(2),       A55(2)/
000005       *  1.392374E+1,-4.921740E+0, 2.065018E-1,-7.579597E-2,           0./
000005         DATA   A61(2),       A62(2),       A63(2),       A64(2),       A65(2)/
000005       *  7.063766E+1,-1.172405E-1, 1.931707E-4,-1.649913E-7,           0./
000005         DATA   A71(2),       A72(2),       A73(2),       A74(2),       A75(2)/
000005       *  1.266986E+1,-1.113379E+1, 2.993128E+0,-4.689769E-1,           0./
000005         DATA   A81(2),       A82(2),       A83(2),       A84(2),       A85(2)/
000005       *  3.537046E+1,-2.496424E-1, 6.623156E-4,-7.941805E-7,3.552154E-10/
000005         DATA   A91(2),       A92(2),       A93(2),       A94(2),       A95(2)/
000005       * -3.070396E+3, 1.966094E+3,-4.728715E+2, 5.054066E+1,-2.024369E+0/
000005         DATA  A101(2),      A102(2),      A103(2),      A104(2),      A105(2)/
000005       * -4.160186E-1, 3.944710E-3,-6.537242E-6, 3.089435E-9,           0./
000005         DATA  A111(2),      A112(2),      A113(2),      A114(2),      A115(2)/
000005       *  6.426501E-3,-7.004641E-6,-7.695759E-9,8.023533E-12,           0./
        C
        C          METHYL ALCOHOL (-140F<T<360F)
        C
000005         DATA   A11(3),       A21(3)/
000005       *        322.7,        32.042/
000005         DATA   A31(3),       A32(3),       A33(3),       A34(3),       A35(3)/
000005       *        1.203,           0.,           0.,           0.,           0./
000005         DATA   A41(3),       A42(3),       A43(3),       A44(3),       A45(3)/
000005       *  8.790546E+2,-2.478105E+0, 6.416629E-3,-7.004195E-6, 2.214439E-9/
000005         DATA   A51(3),       A52(3),       A53(3),       A54(3),       A55(3)/
000005       *  1.505411E+1,-9.240630E+0, 3.366136E+0,-1.969200E+0, 3.389655E-1/
000005         DATA   A61(3),       A62(3),       A63(3),       A64(3),       A65(3)/
000005       *  1.007865E+1, 2.932836E-1,-6.417672E-4, 9.761262E-7,-4.305022E-10/
000005         DATA   A71(3),       A72(3),       A73(3),       A74(3),       A75(3)/
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0005        *  1.593164E+1,-2.109098E+1, 1.144326E+1,-4.278643E+0, 5.809908E-1/
0005         DATA   A81(3),      A82(3),      A83(3),      A84(3),      A85(3)/
0005        *  2.285363E+1,-1.153169E-1, 2.303795E-4,-2.155127E-7, 7.55172E-11/
0005         DATA   A91(3),      A92(3),      A93(3),      A94(3),      A95(3)/
0005        *  1.922596E+2,-1.286769E+2, 3.113344E+1,-3.318410E+0, 1.325051E-1/
0005         DATA  A101(3),     A102(3),     A103(3),     A104(3),     A105(3)/
0005        *  9.944433E-2, 2.097417E-4,-6.310697E-7,7.394364E-10,-3.19696E-13/
0005         DATA  A111(3),     A112(3),     A113(3),     A114(3),     A115(3)/
0005        *  5.790525E-3,-1.404494E-5, 1.205620E-8,3.516629E-12,-8.67029E-15/
      C
      C           FREON-21 (-55F<T<305F)
      C
0005         DATA   A11(4),      A21(4)/
0005        *       248.7,       102.93/
0005         DATA   A31(4),      A32(4),      A33(4),      A34(4),      A35(4)/
0005        *       1.175,           0.,          0.,          0.,          0./
0005         DATA   A41(4),      A42(4),      A43(4),      A44(4),      A45(4)/
0005        *  8.687825E+1, 4.636556E-1,-1.631685E-3, 2.056597E-6,-1.018948E-9/
0005         DATA   A51(4),      A52(4),      A53(4),      A54(4),      A55(4)/
0005        *  3.270732E+0, 1.573170E+1,-1.607959E+1, 5.259243E+0,-6.209501E-1/
0005         DATA   A61(4),      A62(4),      A63(4),      A64(4),      A65(4)/
0005        *  1.332756E+2,-3.261757E-1, 1.111655E-3,-1.611728E-6,6.906674E-10/
0005         DATA   A71(4),      A72(4),      A73(4),      A74(4),      A75(4)/
0005        *  8.534322E+1,-1.662575E+2, 1.252681E+2,-4.265862E+1, 5.375463E+0/
0005         DATA   A81(4),      A82(4),      A83(4),      A84(4),      A85(4)/
0005        * -8.347479E+0, 8.530116E-2,-2.757886E-4, 3.643724E-7,-1.75367E-10/
0005         DATA   A91(4),      A92(4),      A93(4),      A94(4),      A95(4)/
0005        * -1.838588E+3, 1.199366E+3,-2.944711E+2, 3.215076E+1,-1.315728E+0/
0005         DATA  A101(4),     A102(4),     A103(4),     A104(4),     A105(4)/
0005        *  4.750199E-1,-2.403548E-3, 5.713512E-6,-6.391302E-9, 2.65040E-12/
0005         DATA  A111(4),     A112(4),     A113(4),     A114(4),     A115(4)/
0005        * -5.248971E-3, 4.964869E-5,-1.133747E-7,9.235658E-11,-2.25959E-14/
      C
      C           ETHANE (-135F<T<80F)
      C
0005         DATA   A11(5),      A21(5)/
0005        *       161.6,        30.07/
0005         DATA   A31(5),      A32(5),      A33(5),      A34(5),      A35(5)/
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0005          *       1.18,          0.,          0.,          0.,          0./
0005           DATA   A41(5),      A42(5),      A43(5),      A44(5),      A45(5)/
0005          * -4.278934E+3, 4.573254E+1,-1.719481E-1, 2.840439E-4,-1.756889E-7/
0005           DATA   A51(5),      A52(5),      A53(5),      A54(5),      A55(5)/
0005          *  4.513520E+1,-5.803273E+1, 3.388505E+1,-9.165778E+0, 9.154764E-1/
0005           DATA   A61(5),      A62(5),      A63(5),      A64(5),      A65(5)/
0005          * -3.433014E+2, 3.901041E+0,-1.478827E-2, 2.451166E-5,-1.518662E-8/
0005           DATA   A71(5),      A72(5),      A73(5),      A74(5),      A75(5)/
0005          *  9.831080E+1,-1.463731E+2, 8.422928E+1,-2.191841E+1, 2.129803E+0/
0005           DATA   A81(5),      A82(5),      A83(5),      A84(5),      A85(5)/
0005          * -1.723943E+1, 1.931920E-1,-7.953422E-4, 1.385103E-6,-8.90506E-10/
0005           DATA   A91(5),      A92(5),      A93(5),      A94(5),      A95(5)/
0005          *  2.999855E+4,-2.017435E+4, 5.085813E+3,-5.697099E+2, 2.392870E+1/
0005           DATA  A101(5),     A102(5),     A103(5),     A104(5),     A105(5)/
0005          * -1.142860E+0, 1.317096E-2,-5.072525E-5, 8.390294E-8,-5.11860E-11/
0005           DATA  A111(5),     A112(5),     A113(5),     A114(5),     A115(5)/
0005          *  1.123709E-2,-8.339622E-5, 2.759121E-7,-4.39343E-10,2.65146FE-13/
      C
      C          METHANE (-250F<T<-120F)
      C
00005          DATA   A11(6),      A21(6)/
00005         *      163.2,       16.04/
00005          DATA   A31(6),      A32(6),      A33(6),      A34(6),      A35(6)/
00005         *       1.32,          0.,          0.,          0.,          0./
00005          DATA   A41(6),      A42(6),      A43(6),      A44(6),      A45(6)/
00005         * -1.124091E+3, 2.425142E+1,-1.589307E-1, 4.547110E-4,-4.908714E-7/
00005          DATA   A51(6),      A52(6),      A53(6),      A54(6),      A55(6)/
00005         *  1.365684E+0, 8.557617E+0,-3.746570E+0, 5.803347E-1,-3.257158E-2/
00005          DATA   A61(6),      A62(6),      A63(6),      A64(6),      A65(6)/
00005         *  1.460051E+1, 3.614831E-1,-3.223542E-3, 1.076420E-5,-1.353123E-8/
00005          DATA   A71(6),      A72(6),      A73(6),      A74(6),      A75(6)/
00005         *  6.381082E+1,-5.455063E+1, 1.837493E+1,-2.799046E+0, 1.567545E-1/
00005          DATA   A81(6),      A82(6),      A83(6),      A84(6),      A85(6)/
00005         * -9.526486E+0, 2.024132E-1,-1.540820E-3, 4.719715E-6,-5.211675E-9/
00005          DATA   A91(6),      A92(6),      A93(6),      A94(6),      A95(6)/
00005         *  9.119631E+3,-6.766529E+3, 1.880522E+3,-2.321565E+2, 1.074409E+1/
00005          DATA  A101(6),     A102(6),     A103(6),     A104(6),     A105(6)/
00005         *  3.486478E-1,-1.720959E-3, 3.699297E-7, 1.840747E-6,-3.73323E-11/
```

```
00005         DATA  A111(6),      A112(6),      A113(6),      A114(6),      A115(6)/
C0005         *  5.412797E-3,-5.463947E-5, 2.856240E-7,-7.81700E-10,8.146495E-13/
        C
        C          NITROGEN (-340F<T<-250F)
        C
00005         DATA   A11(7),       A21(7)/
00005         *       113.9,        28.016/
00005         DATA   A31(7),       A32(7),       A33(7),       A34(7),       A35(7)/
00005         *       1.40,          0.,           0.,           0.,           0./
00005         DATA   A41(7),       A42(7),       A43(7),       A44(7),       A45(7)/
00005         *  7.648974E+1,-2.305556E-1, 5.317599E-3,-2.340715E-5,          0./
00005         DATA   A51(7),       A52(7),       A53(7),       A54(7),       A55(7)/
00005         *  3.217173E+1,-1.431289E+1, 3.064764E+0,-3.133777E-1, 1.176449E-2/
00005         DATA   A61(7),       A62(7),       A63(7),       A64(7),       A65(7)/
00005         *  7.298716E+1,-3.323232E-1, 2.281469E-3,-7.478632E-6,          0./
00005         DATA   A71(7),       A72(7),       A73(7),       A74(7),       A75(7)/
000005        *  2.102802E+1,-7.503727E+0, 9.613273E-1,-4.861116E-2,          0./
C00005        DATA   A81(7),       A82(7),       A83(7),       A84(7),       A85(7)/
000005        * -1.130709E+1, 3.580937E-1,-3.880943E-3, 1.687014E-5,-2.609266E-8/
000005        DATA   A91(7),       A92(7),       A93(7),       A94(7),       A95(7)/
000005        *  1.718670E+4,-1.371991E+4, 4.103945E+3,-5.453515E+2, 2.716624E+1/
000005        DATA  A101(7),      A102(7),      A103(7),      A104(7),      A105(7)/
000005        *  1.178000E-1,-7.992424E-5,-1.401515E-6,           0.,          0./
000005        DATA  A111(7),      A112(7),      A113(7),      A114(7),      A115(7)/
000005        *  1.636031E-3,-3.768939E-6,-4.379371E-8,1.270396E-10,          0./
        C
000005        IF (L.EQ.0) GO TO 20
        C
000006        T2 = T*T
000007        T3 = T2*T
000011        T4 = T2*T2
000013        TR = 1000./T
000015        TR2 = TR*TR
000017        TR3 = TR2*TR
000021        TR4 = TR2*TR2
000023        ALT=ALOG(T)
000027        ALT2=ALT*ALT
000031        ALT3=ALT2*ALT
```

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```
00033          ALT4=ALT2*ALT2
       C
       C          FLUID PROPERTIES
       C
00035          TF = A11(L)
00037          XMW=A21(L)
00041          SHPV = A31(L)+A32(L)*T+A33(L)*T2+A34(L)*T3+A35(L)*T4
00053          HFG = A41(L)+A42(L)*T+A43(L)*T2+A44(L)*T3+A45(L)*T4
00065          PV = EXP(A51(L)+A52(L)*TR+A53(L)*TR2+A54(L)*TR3+A55(L)*TR4)
00103          RHOL = A61(L)+A62(L)*T+A63(L)*T2+A64(L)*T3+A65(L)*T4
00115          RHOV = EXP(A71(L)+A72(L)*TR+A73(L)*TR2+A74(L)*TR3+A75(L)*TR4)
00133          VISL = EXP(A81(L)+A82(L)*T+A83(L)*T2+A84(L)*T3+A85(L)*T4)
00151          VISV = EXP(A91(L)+A92(L)*ALT+A93(L)*ALT2+A94(L)*ALT3+A95(L)*ALT4)
00167          XKL = A101(L)+A102(L)*T+A103(L)*T2+A104(L)*T3+A105(L)*T4
00201          ST = A111(L)+A112(L)*T+A113(L)*T2+A114(L)*T3+A115(L)*T4
00213          VISV = VISV/4.1697504E8
00215          VISL=VISL/4.1697504E8
00217          RETURN
       C
00220       20 CONTINUE
00220          RETURN
00221          END
```

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UNX COMPILER (VER.2.3M)                 09/28/76. 13.05.23.

              SUBROUTINE SANF(A,P,W0,W1,W2,W3,V0,V1,V2,V3,AA)
000016        R=SQRT((V1-V3)**2+(W1-W3)**2)
000032        THETA=ACOS(((W3-W1)*(W2-W1)+(V3-V1)*(V2-V1))/
000032       1      SQRT(((W3-W1)**2+(V3-V1)**2)
000032       2      *((W2-W1)**2+(V2-V1)**2)))
000067        P=R*THETA
000071        A023=.5*ABS((W2*V3-V2*W3)-(W0*V3-V0*W3)+(W0*V2-V0*W2))
000107        A12B3=.5*THETA*R*R
000112        A123=.5*ABS((W2*V3-V2*W3)-(W1*V3-V1*W3)+(W1*V2-V1*W2))
000130        A=A023+A12B3-A123-AA
000134        RETURN
000135        END
```

```
       SUBROUTINE SIMPSN(X,Y,AA,SF,ALPHA,DALPHA,XO,YO,ALPHAO)
000014 CALL DRV(ALPHA,DX1,DS1,DA1,X,Y,XO,YO,ALPHAO)
000032 ALPHA=ALPHA+DALPHA/2.
000035 X1=X+(DX1/2.)*DALPHA
000041 CALL DRV(ALPHA,DX2,DS2,DA2,X1,Y,XO,YO,ALPHAO)
000057 ALPHA=ALPHA+DALPHA/2.
000062 X2=X+DX2*DALPHA
000065 CALL DRV(ALPHA,DX3,DS3,DA3,X2,Y,XO,YO,ALPHAO)
000103 X=X+(DX1+4.*DX2+DX3)*DALPHA/6.
000112 AA=AA+(DA1+4.*DA2+DA3)*DALPHA/6.
000121 SF=SF+(DS1+4.*DS2+DS3)*DALPHA/6.
000130 RETURN
000131 END
```